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development of the
unitary steam engine
(project H-3314-1A)

PROTOTYPE DEVELOPMENT OF THE UNITARY STEAM ENGINE (PROJECT H-3314-1A)

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PROTOTYPE DEVELOPMENT OF THE UNITARY STEAM ENGINE

(PROJECT H-3314-1A)

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February, 1988

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A project, located in Butte, Montana, to develop a working prototype of a steam engine for use as a prime mover. The device includes an expander, boiler, combustor, condenser, and pumps necessary for a working model that would utilize a biomass generated fuel alcohol as its renewable energy resource. Detailed design basis, working drawings, engineering analysis and supporting design documentation are provided. Component fabrication and subsequent assembly provided the working prototype for operational testing.

This report was prepared under an agreement funded by the Montana Department of Natural Resources and Conservation. Neither the Department nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe on privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Department of Natural Resources and Conservation or any employee thereof. The reviews and opinion of authors expressed herein do not necessarily state or reflect those of the Department or any employee thereof.

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APPENDIX F -- DRAWING INDEX, PART NUMBERS, AND BILL OF MATERIALS

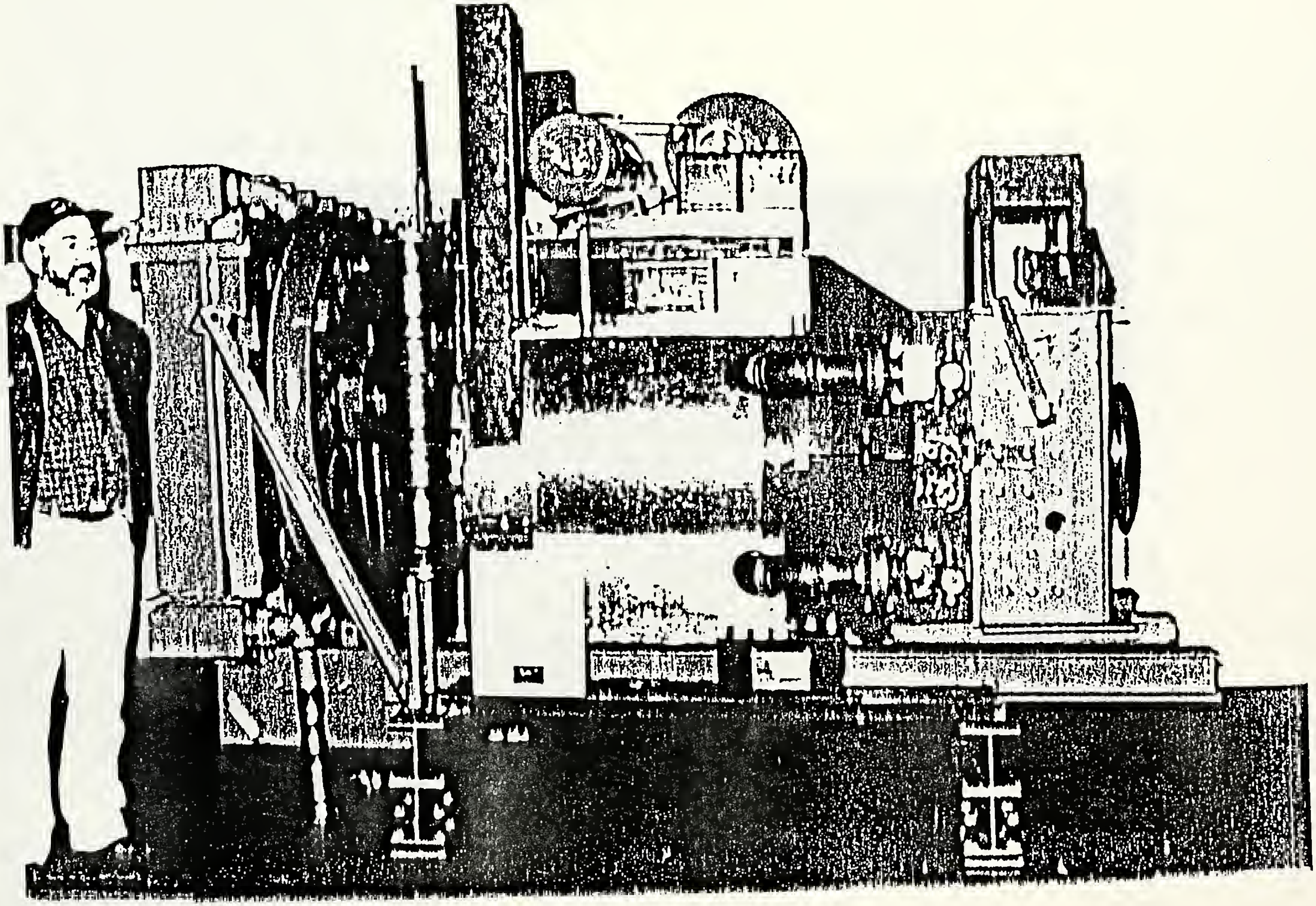
NOTE: APPENDIX B THROUGH F ARE DNRC OFFICE COPIES ONLY

ABSTRACT

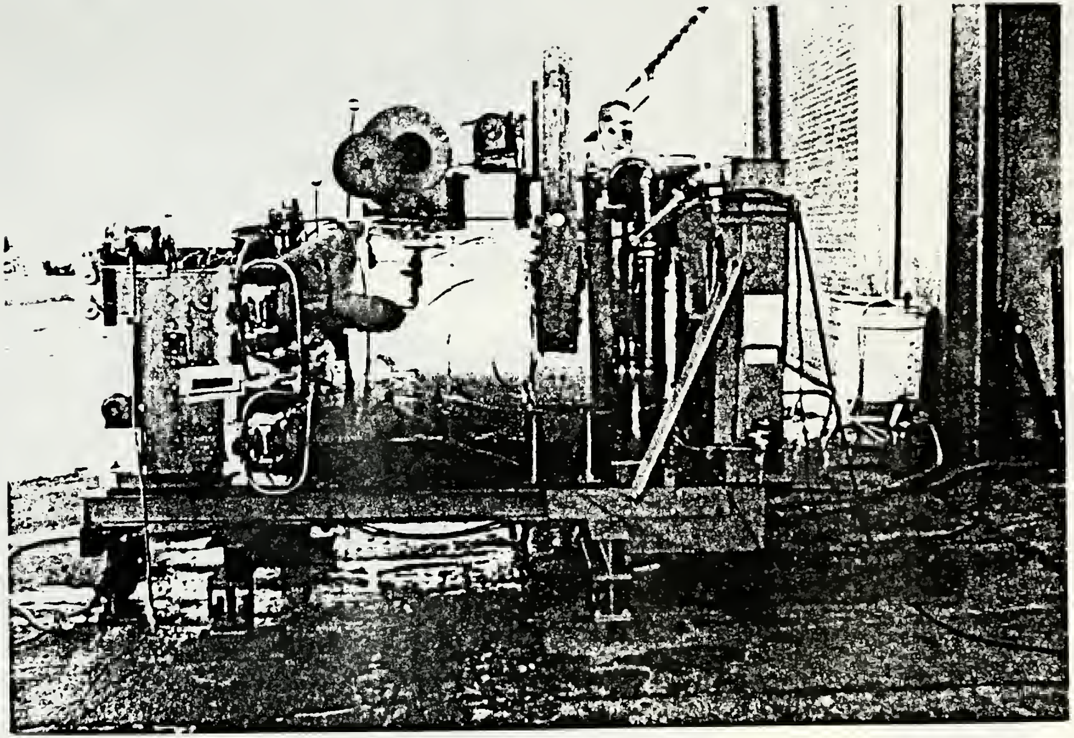
Cozby Enterprises, Inc., with technical support from the MultiTech Services Division of MSE, Inc. and under grant agreement with the Department of Natural Resources and Conservation, has developed a prototype of the patented Unitary Steam Engine (Engine). The project's objectives were to provide the design basis and design documentation necessary to validate the design requirements of the prototype as well as fabricate and assemble the engine, which was performance tested and operated.

The initial project work was designing in detail the expander, boiler, combustor, pumps, condenser, and auxiliaries. This included engineering assumptions and calculations; working drawings; equipment descriptions; mass, energy, and flow diagrams; and performance monitoring requirements. The Engine components were fabricated based on these designs, and the complete Unitary Steam Engine was assembled.

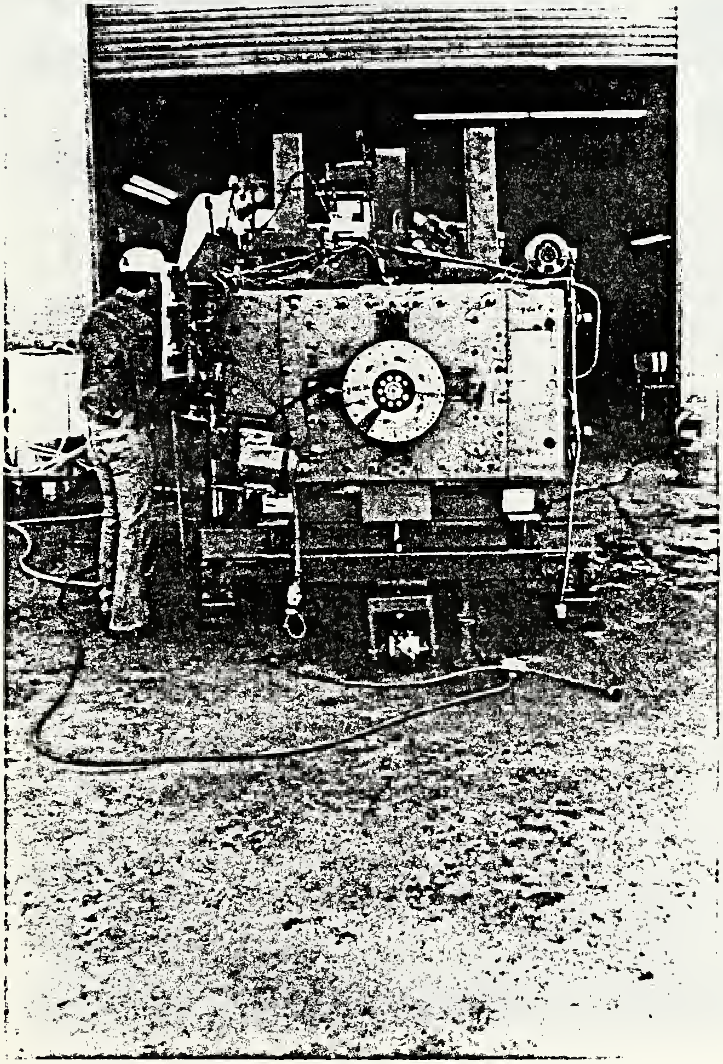
The Engine was checked for clearances and operated for proof of concepts as follows: The combustor was fired for combustion concept proof; steam was generated for heat transfer concept; the throttle was operated successfully to transfer steam to the expander; the expander assembly failed to perform as contemplated due to a number of mechanical and material malfunctions. Due to this malfunction, it was impossible to compare test results to overall design efficiencies. A pictorial record of the fabrication, assembly, and testing is available in a documented slide show.



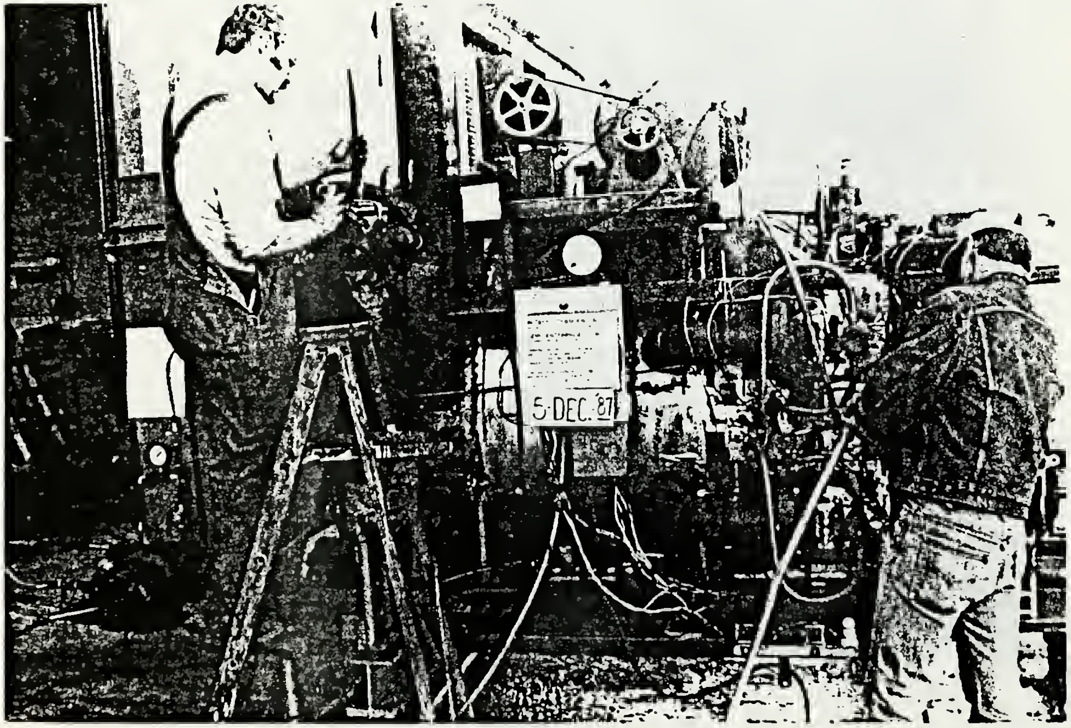
U.S. ENGINE 80% COMPLETE, JULY 1987



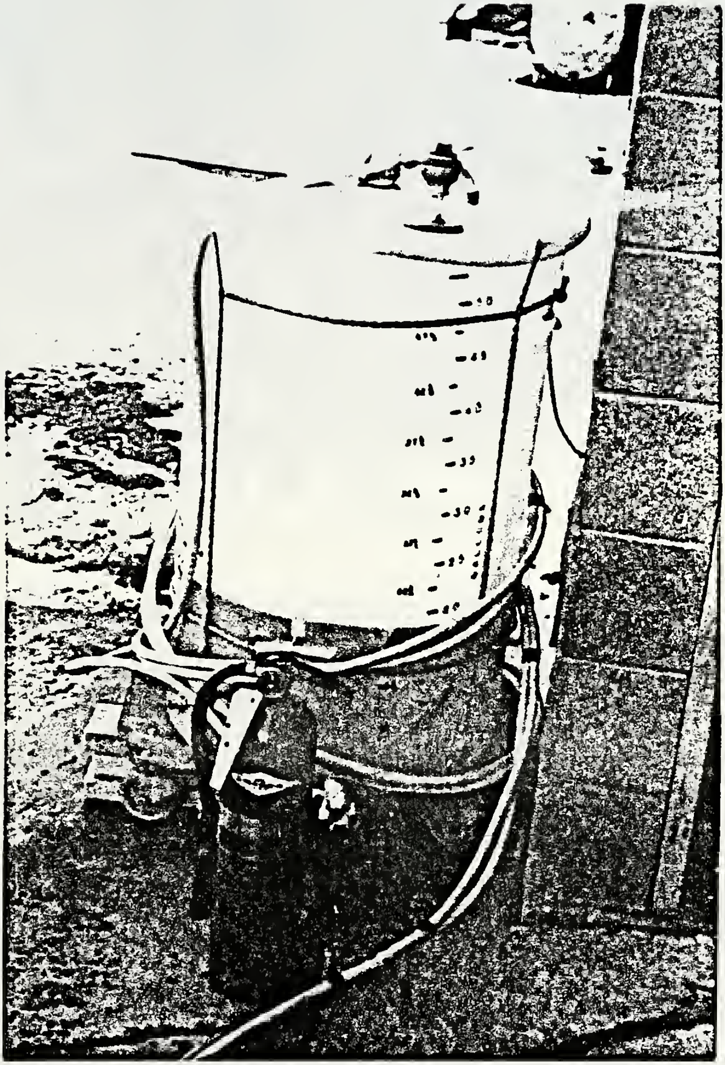
Right Side View of Unitary Steam Engine on December 5, 1987 - Before Test



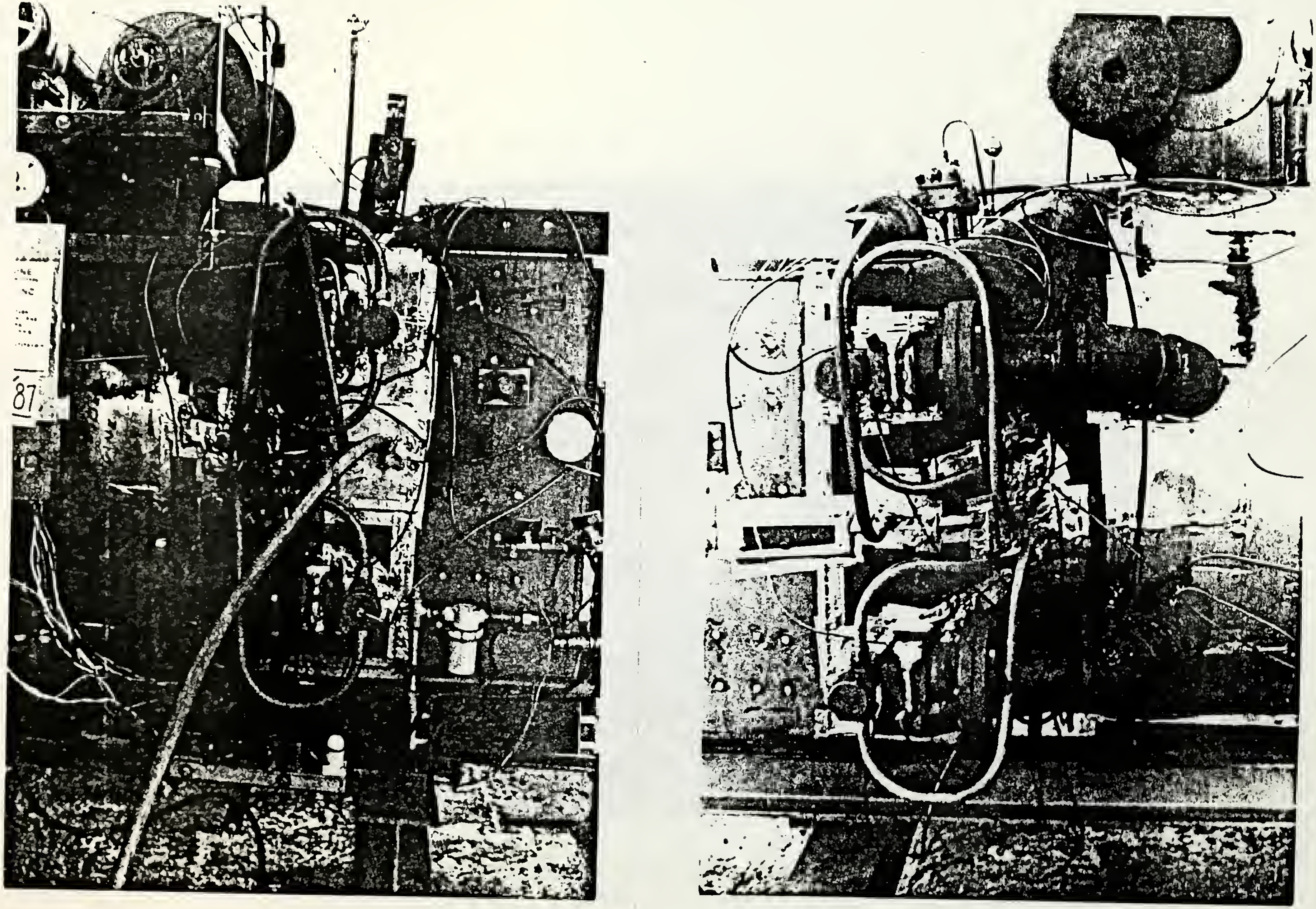
Unitary Steam Engine Flywheel - Power Take Off (Back View of Engine)



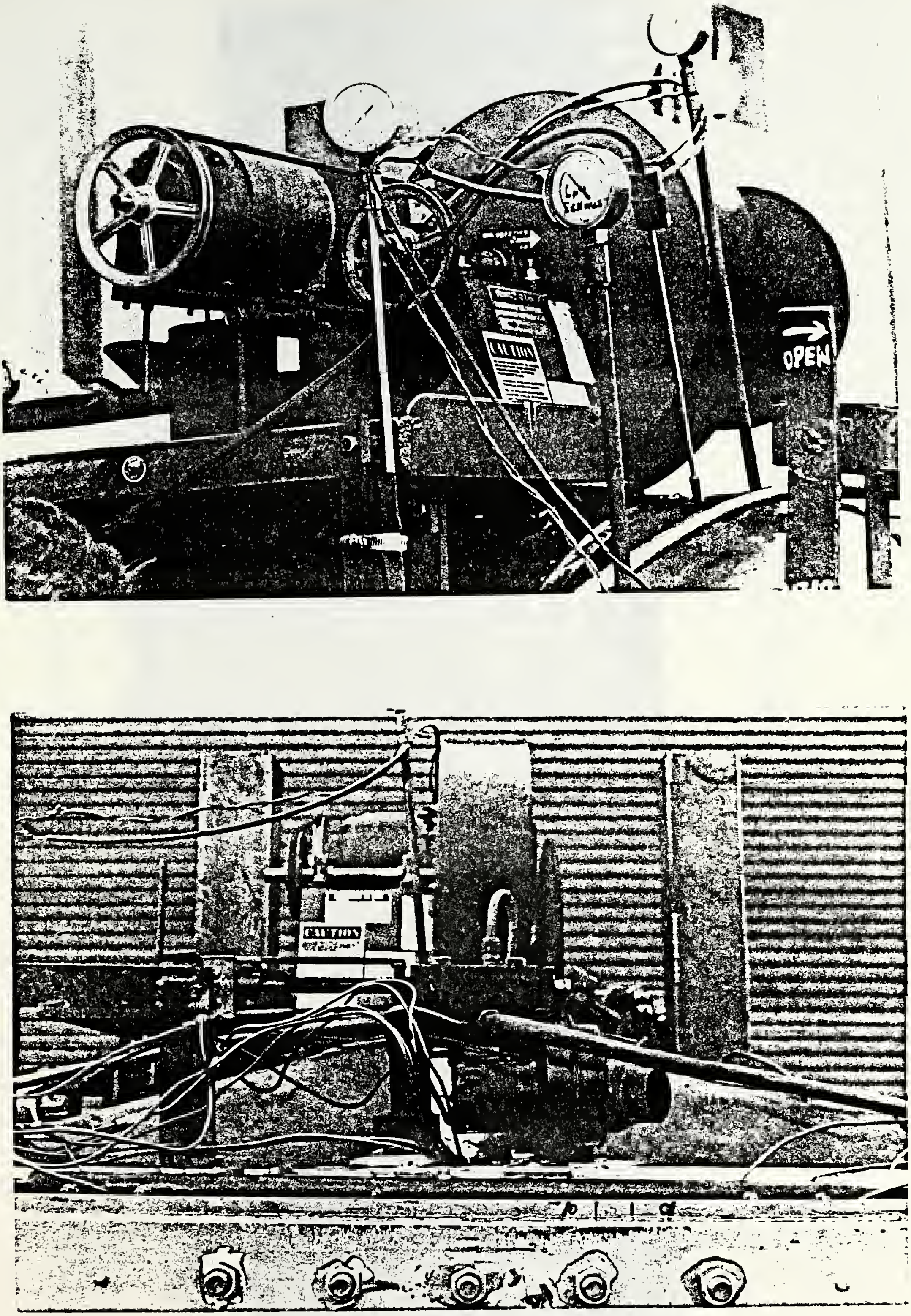
Left Side View of Unitary Steam Engine While Charging Boiler Tubes
For Test on December 5, 1987



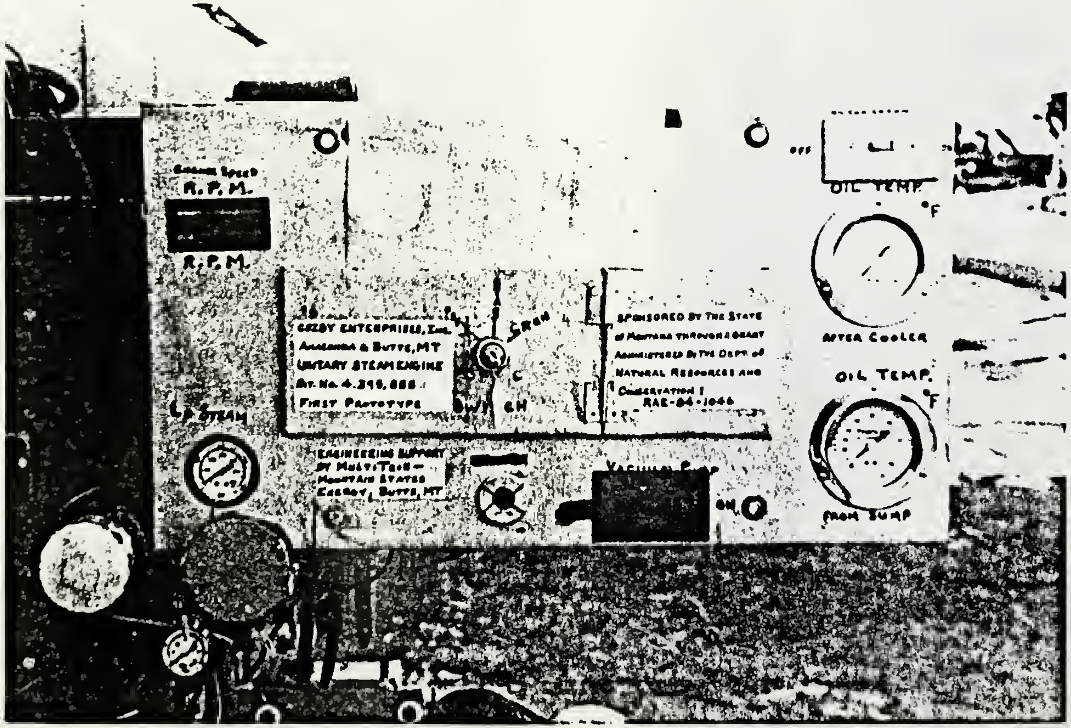
Fuel Oil Tank and Lines



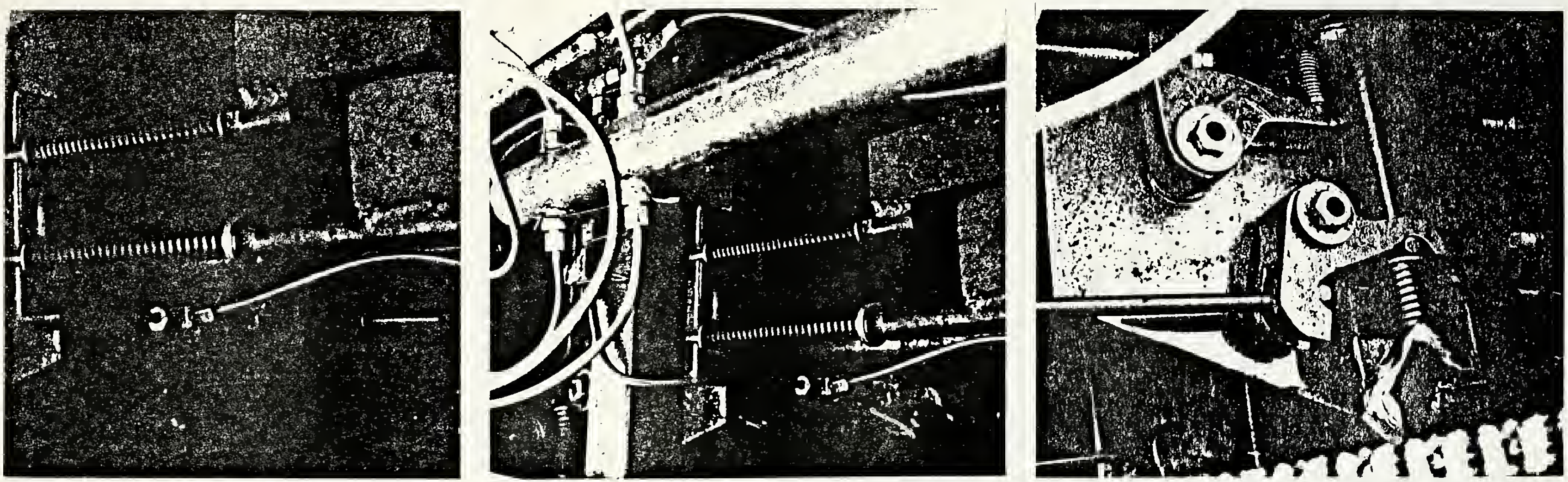
Left and Right Side Views of Transition Piece From Boiler to Engine That Will Be Modified in Future Versions



Left (Top) and Back (Bottom) Views of Forceol Draft Blowers



Unitary Steam Engine Control Panel With Oil Filters on the Lower Left



View Inside Engine With Top Off From Left to Right.
Chain On Right Drives The Lubricating Oil Pump

1.0 INTRODUCTION

This section of the report describes the history of the Unitary Steam Engine, including the development accomplished prior to this DNRC contract. It also covers the steps necessary to achieve commercial production. General concepts pertinent to the Unitary Steam Engine (Engine) are discussed in detail.

1.1 PROJECT HISTORY

In late 1966, a brainstorming session generated the idea of producing a more efficient engine, probably some form of steam engine. Different engine options and their comparative strengths and weaknesses were investigated during 1967 and 1968. That research established the reciprocating piston steam engine as the most promising direction for further development.

In the following ten years, further research and inventive effort resulted in an Engine concept with all the general parameters established. In March 1978, this engine concept was disclosed to the Center for Innovation (CFI) in Butte, Montana. CFI evaluated the engine and contacted an attorney for a patent search. After the patent search, there was more research and inventive development to detail specific thermal and mechanical limits. An application for the Engine patent was filed on October 8, 1981. That United States Patent 4,395,885 approved August 2, 1983 is included in Appendix A. During this time, those individuals who were responsible for developing the Engine incorporated as Cozby Enterprises, Inc.

After the patent application was filed, work was directed to refining engineering data. Independent evaluations of the Unitary Steam Engine were obtained to establish feasibility, practicality, and commercial potential. Evaluations came from the Alliance for American Inventors, Department of Commerce Office of Energy Related Inventions, and Department of Army Mobility Equipment Research and Development Command. Work was begun to attract funding. A proposal to build a working prototype Unitary Steam Engine to be fired with a renewable energy fuel was presented to the Department of Natural Resources and Conservation (DNRC) on October 31, 1983.

On June 14, 1984, Cozby Enterprises, Inc. signed a grant agreement with DNRC to build and test the prototype engine. The project was to be completed in nine stages of work. This is the final report which marks completion of the project.

1.2 COMMERCIALIZATION SCHEDULE

For the Engine to become commercially available, research and development will be necessary according to the following schedule:

1966-1981 - Preliminary Design - Completed
1981-1984 - Detailed Design - Completed
1983-1987 - Prototype Funding - Completed
1985-1987 - Initial Prototype - Completed
1988 - Funding Solicitation
1988-1989 - In-Depth Engineering Analysis
1989 - Funding Solicitation
1989-1990 - Second Prototype Development
1990-1991 - Testing - Failure
  -Pressure
  -Stress
  -Wear
 -Performance
  -Emissions
  -Effluents
  -Power
  -Controls
 -Life
  -Laboratory
  -Field
1991 - Funding Solicitation
1991-1992 - Third Prototype Development
1992-1993 - Test - Repeat 1990 Series
1993 - Funding Solicitation
1993-1994 - Manufacturing Engineering
1995 - First Production Run

1.3 ENGINE CONCEPT

The Unitary Steam Engine is a complex and involved invention, which is a synergistic system both mechanically and thermodynamically. It is capable of mass production with present technology and materials. The Engine is capable of the same functions as present generation engines, but has greater capacity for high thermal efficiencies, low exhaust emissions, high performance, quietness, and diversified fuel use. The Engine is a reciprocating piston, high speed, balanced, horizontal opposed, modified double-acting, short stroke, cam-operated slide valve, multi-cylinder, multi-stage, condensing engine. It operates on the improved Rankine cycle in a closed fluid system. It incorporates furnace heated engine cylinders and multiple receiver reheats between stages, as well as high initial superheat. The Engine is equipped with variable high pressure cut-off and high pressure cylinder by-pass for high overload capacity. It is capable of high ratios of expansion and high flow rates and incorporates an "engine brake" capable of retarding or stopping the Engine and load.

The expander is designed to operate in conjunction with a highly efficient boiler package; that package includes: 1) a boiler-furnace; 2) superheater; 3) multiple stage re-heater; 4) cylinder heater; 5) recuperator; 6) economizer; 7) regenerator; and 8) insulation. The system is also designed to operate with an evacuated, deaerated condensing system. The design incorporates many desirable qualities of older steam engines, present internal combustion engines, and steam turbine system technology. Despite the considerable complexity involved in the design, simplicity and practicality of operation are two primary benefits of the Unitary Steam Engine.

Safety was an important consideration in the Engine design. The Engine is designed to operate with pressures up to 2,800 pounds per square inch (psi). This is not high pressure considering that many commercially available boilers produce 10,000 psi at 1,400^{o}F. In the past, boilers on locomotives, steamboats, and threshing machines blew up while operating on saturated steam in the 90 psi to 120 psi range. However, modern Rankine cycle engines appear to be safe without qualification according to the Department of Energy's Assessment of the Technology of Rankine Engines for Automobiles. The use of monotube boilers effectively removes boiler explosion as a potential problem. The rest of the engine will differ little as far as safety from the spark ignition engine it replaces. The findings of the Assessment apply to the Unitary Steam Engine because the mechanical structures and steam pressures are similar.

A hazard of heat engines is the by-products of combustion. Carbon monoxide, a poisonous gas, is a common product of gasoline engines. Particulate emissions, which are thought to be associated with some forms of cancer, are produced in the diesel cycle. The complete combustion process as normally found in the furnace of a steam boiler produces practically no harmful emissions.

The engine's controls are an important factor in safety because operator error can be a cause of loss of life or limb. Therefore, it is always best to simplify designs for the easiest possible operation. This requires a build-in of safeguards and a design as automatic as is practical. For this reason, this Engine design requires the operator to have only a basic knowledge of this system to safely operate it. When the ignition switch is on, the critical functions engage and are automatically and continually controlled and maintained within safe limits. The engine functions carried on without requiring the operator to know or understand them include: ignition and flame control; fuel and air metering and mixture; water level and pumping cycle; pressure and heat generation; furnace temperature; engine overspeed; and over-pressure protection.

The Unitary Steam Engine will have some manual controls, such as those listed below, and these will require operator understanding.

- Opening the throttle fully will substantially increase power.

- Point of cut-off can be adjusted by a lever to achieve best economy or higher power output.

- The cut-off lever will also function to allow the operator to slow or stop the load by using the engine as a brake.

There will be a gauge to indicate water level on the condenser hot well, and temperature, and pressure gauges that the operator needs to monitor for safe and reliable operation.

2.0 RESULTS AND DISCUSSIONS

This section discusses the results of the work accomplished during the contract period, and outlines pertinent findings and recommendations.

2.1 FINDINGS AND RECOMMENDATIONS

Data generated during the course of this project have confirmed the preliminary information provided in the proposal of October 31, 1983. The Unitary Steam Engine was proven to be a feasible concept which can proceed to commercialization. The following paragraphs outline conclusions that resulted in modifications to the original design.

Because of the high speeds possible on the engine's cross arm, the fuel injector that was to have been mounted on the cross arm was deleted from the design. The engine's fuel is pumped by an auxiliary fuel pump.

The liquid level controller has been modified to include the steam separator function and makes use of available relays and controls for regulation of the furnace and boiler pressure.

Calculations relative to the recuperator indicate that the regenerative feedwater heat pump may not be cost effective in this prototype Engine. Therefore final design and development of the regenerative feedwater heat pump has been postponed pending empirical data showing the amount of heat recuperated to the feedwater.

The condenser fan design was modified to incorporate a hydraulic motor drive and control system, allowing a variable cooling rate.

There have not been any major construction changes that would substantially alter the basic design of the Engine or its operation. Those changes are summarized in Appendix B.

2.2 CONSTRUCTION METHODOLOGY

Standard machine shop practice was used to make the parts that were assembled into the prototype Unitary Steam Engine. Where appropriate, work was done by subcontract; for instance the custom manufacture of the crankshaft, the flame cutting of certain parts, and the specialty shop manufacturing of parts.

Most of the tools needed to build the Engine were already on hand. Machine tools used to complete the project included a 15" lathe, a 16" vertical mill, a drill press, a 250 amp continuous duty arc welder, and a power band saw.

2.3 TESTING

Testing data and information generated during the construction, assembly, and performance evaluation have contributed to the further development of the Unitary Steam Engine.

Testing included continual checking and fitting of parts and assemblies to insure proper mechanical operation as well as the formal operational tests.

Power output was not tested because the Engine did not operate long enough to yield that data. Specific test or performance results are included in Appendix C, Test Data, while many other test procedures are presented within the text of the Chronological Test Report/Weekly Progress Reports in Appendix D.

2.4 PERFORMANCE DISCREPANCIES

The major performance discrepancies were the time required and subsequent cost overruns to complete the actual fabrication and construction of the Engine. The inability to provide the projected operational test data for continuous longer term operation was also a discrepancy.

The project encountered many of the usual problems that would be expected in the planning, organizing, and implementation of a project of this extent. This included such items as project start-up, office relocation, personnel availability, man-hour estimate variations, material and material cost estimate variations, line-of-credit requirement, shop and liability insurance, workers compensation and unemployment insurance, FICA payments, budget constraints, and lack of a project contingency allowance.

Specifically, the following were the more notable contributors to the time, cost, and performance discrepancies:

- Subcontracted work frequently did not meet requirements
- Material delivery delays
- Availability of specified material
- Finance costs incurred with line-of-credit
- Prototype machining and fitting
- Debugging
- Prototype design modifications
- Material problems
  - Astralloy was not readily machinable
  - Difficulty of machining ceramics
  - Fragile nature of ceramics
  - Ceramic performance limitation
  - Copper tubing work failures
  - High temperature sealing compound failures
  - Valve seat corrosion
- Component problems
  - Piston ceramic breakage
  - Throttle replacement
  - Valve ceramic breakage
  - Valve springs and retainers
  - Valve lubrication
  - 32-volt charging system
  - Start-up lubrication need
  - Start-up fuel requirement
  - Burner cone design
  - Fuel pump change
  - Modified ignition system
  - Pulsation damper and check valve failure
  - Cam and cam follower mating

None of the foregoing were insurmountable and should not prevent further development and fabrication of a satisfactory working prototype. Many of these and other changes or modifications are outlined in Appendix D, Summary of Construction Changes.

2.5 ADDITIONAL DEVELOPMENT

In any developmental work, tests are designed to discover problems and weaknesses. When the nature of a problem is understood, it can be corrected. Work can then proceed to refine the design and proceed toward commercial production. This project was one of the sequential steps in the plan to bring the Unitary Steam Engine into commercial production. Additional developmental work is required to obtain that end. An abbreviated outline of that plan follows:

DEVELOPMENTAL STEPS

I. DNRC Prototype-Completed
II. Second Generation Prototypes
    A. Engineering Drawings
    B. Construction
    C. Testing
    D. Analyses
III. Manufacturing or Third Generation Prototype
    A. Engineering Drawings
    B. Construction
    C. Testing
    D. Analyses
IV. Pre-Manufacture
    A. Marketing Analysis
    B. Business Plan
    C. Manufacturing Analysis
    D. Funding

V. Factory construction
   - A. Engineering Design
   - B. Construction
   - C. Tooling
   - D. Startup

VI. Manufacture

Although considerable development work remains to be done, no major problems are foreseen if sufficient funding can be obtained to proceed. This project was limited to proof-of-concept and initial operating test data and was actually underfunded for the scope of work completed. Development work directed toward improvements in design characteristics, long-term testing, and special applications will be a separate project with new funding.

Follow-on work to determine the causes of failure in this prototype needs to be done so modifications can be incorporated into the next Engine. An extensive disassembly examining all of the component parts must be accomplished to determine the effects of testing and allow failure analysis to proceed.

Test-stand models must be built in order to properly investigate valve motion effort and resistance. This will allow any redesign work to be tested before incorporation into the complete Engine. This also will allow material investigation in order to make the best choice for this application.

During second or third stage prototype development, a more extensive materials analysis will be undertaken to find the optimum materials for each application. Destructive testing on future engines will indicate areas of over-engineering where weight can be reduced. Testing may indicate desirable dimensional alterations, such as a longer high pressure cam region on the crankshaft.

The expander's intermediate pressure stage requires redesign to improve construction methodology and reduce potential operational problems. Possible use of castings should be considered for many of the components. Method of manufacture and assembly of the transition piece requires investigation as well as all sealing applications.

As designed, the steam generator was adequate to power this prototype. Future designs will refine output and design parameters to deliver steam that is optimum for a specific application of the Engine. Furnace and burner design modifications are anticipated to improve heat delivery and combustion efficiency. Future development work will also focus on weight reduction and material savings. Use of a solid fuel combustor is highly desirable and must be incorporated.

In-depth study and analysis of the condenser and the condenser fan will be required to improve specific output characteristics for production model engines.

Additional development will be required to determine what cycle improvement would occur from regenerative feedwater heat pumping. Other planned future developments to attain highest thermal efficiencies include a four-stage engine of similar design to the present three stage prototype; three re-heat modes; greater expansion ratio providing for increased initial pressure; three regenerative steam bleeds for feedwater heating; and higher super-heat and re-heat values.

These future developments are anticipated to eventually achieve realizable thermal efficiencies in the 45% to 50% range, or possibly even slightly better

A separate prototype investigation must be done to develop the radial design Unitary Steam Engine. This Engine design is envisioned as being smaller and less expensive.

3.0 SYSTEM DESIGN

3.1 MASS, ENERGY, AND FLOW BALANCES

This section deals with the principles of thermodynamics in the conversion and transfer of heat energy. A flow diagram and data generated prior to this project was used as the basis for starting the thermodynamic calculations. Following investigation of the various principles, more appropriate process flow diagrams with mass and energy balances were developed to substantiate the concept of the Unitary Steam Engine.

3.1.1 Process Flow Diagram

The Steam Generator Heat Balance, Drawing 00-80-003-B, relates to the Engine's heat and mass balances. The drawing area including the identifiers Hp, Ip, and Lp pertains to the expander subassembly. This includes the superheated steam at 2,800 psia and 1,200°F as received from the steam generator and consecutively expanded through the high pressure (Hp), intermediate pressure (Ip), and low pressure (Lp) stages with reheats interposed between the stages. This flow is indicated as Point 1 through Point 6 of this drawing.

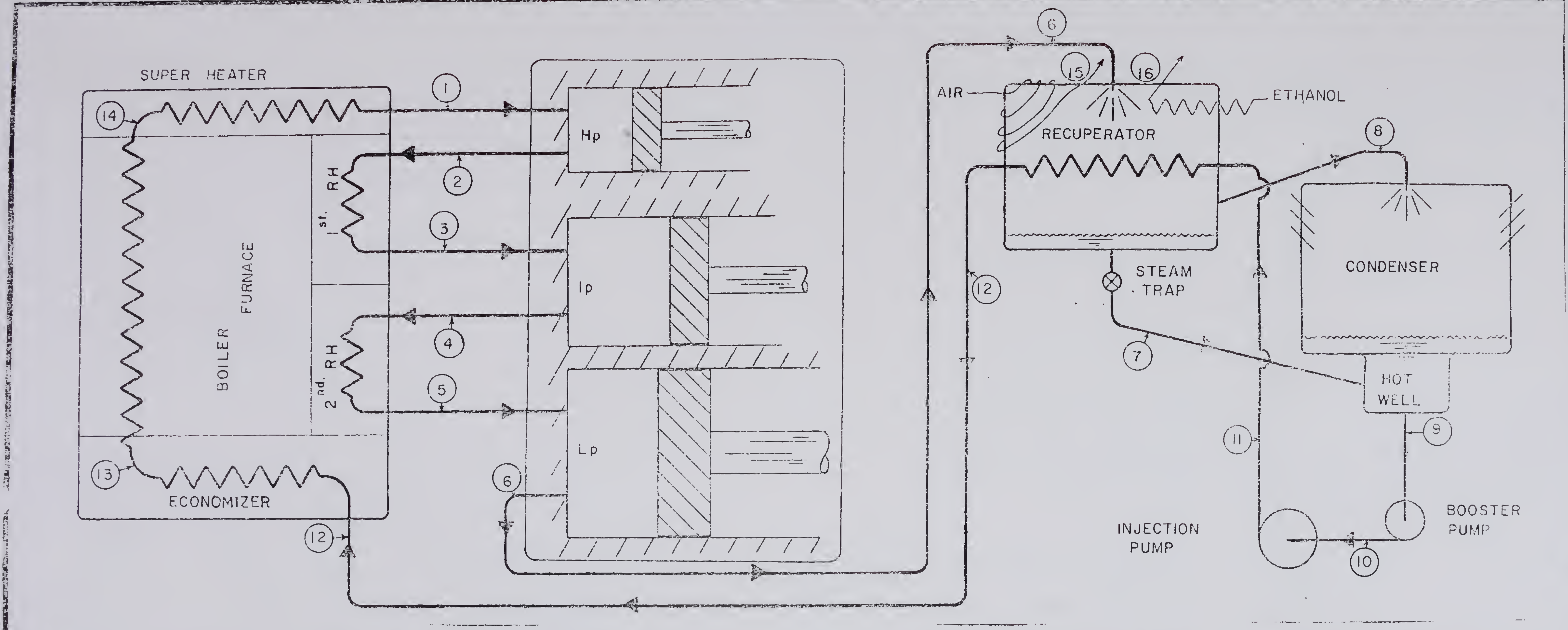
The steam generator subassembly is that portion of this drawing bearing the identifiers economizer, boiler/furnace, superheater, 1st reheat (RH), 2nd RH, and recuperator. Points 1 through 8 and 11 through 16 are pertinent to the operation of the steam generator.

The condenser subassembly is represented by the identifiers Condenser and Hotwell. Points 8 and 9 are pertinent to the operation of the condenser.

Auxiliaries are represented in the diagram by the identifiers Booster Pump and Steam Trap.

3.1.2 Thermodynamic Principles

Thermodynamics is the general study that deals with the concepts and laws that describe the conversion of one form of energy to another form of energy. The



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TEMPERATURE °F	1200	591	1200	592	1200	439	116	116	102	102	109	439	685	685	388	382
PRESSURE PSIA	2800	375	375	47.3	47.3	5.0	1.5	1.5	1.0	250	2800	2800	2800	2800	15.7	400
ENTHALPY Btu/lb	1579.3	1304.0	1631.7	1329.2	1638.7	1260.0	83.7	1111.7	69.7	70.4	78.1	420.8	770.7	1055.8	79.48	11,731
ENTROPY Btu/lb °R	1.5938	1.5938	1.8399	1.8399	2.0715	2.0715	0.1571	1.9438	0.1326	0.1327	0.1455	0.6070	0.9468	1.1958	———	———
SPECIFIC VOLUME ft³/lb	0.3268	1.5663	2.6112	13.1828	20.9324	299.5	0.01619	227.7	0.01614	0.01613	0.01616	0.0190	0.03134	0.10305	20.06	0.02427
MASS/CYCLE lb/cyc	0.002355	0.002355	0.002355	0.002355	0.002355	0.002355	0.000455	0.001910	0.002355	0.002355	0.002355	0.002355	0.002355	0.002355	0.003656	0.000386
ENTHALPY/CYCLE Btu/cyc	3.7193	3.0709	3.8427	3.1303	3.8591	2.9673	0.0372	2.1233	0.1641	0.1658	0.1839	0.9910	1.8151	2.4865	0.29057	0.0772

△: MASS, ENTHALPY on ⑦ ⑧ : by MC 10-30-84.
DESIGNED A. MILLER
DRAWN MJM 9-27-84
CHECKED
APPROVED
APPROVED

MULTITECH FOR COZBY ENTERPRISES
P.O. BOX 4078
BUTTE, MT
P.O. BOX 700
ANACONDA, MT
UNITARY STEAM ENGINE, Project H-3314-1A, DNRC RAE-84-1046
STEAM GENERATOR
HEAT BALANCE
Scale NONE
00-80-003-B
Rev. △

FLOW DIAGRAM AND MATERIAL BALANCE – FOR 1/8 CUT OFF Hp STAGE

MULTITECH, INC.
Butte, Mt.

Unitary Steam Engine is analyzed as a system in equilibrium operating through a closed Rankine cycle.

The first law of thermodynamics is that energy can neither be created or destroyed and whenever energy is transformed from one form to another, energy is always conserved. In a steady-flow process such as the Unitary Steam Engine the mass rate of energy flow into the apparatus is equal to the mass rate of energy flow out.

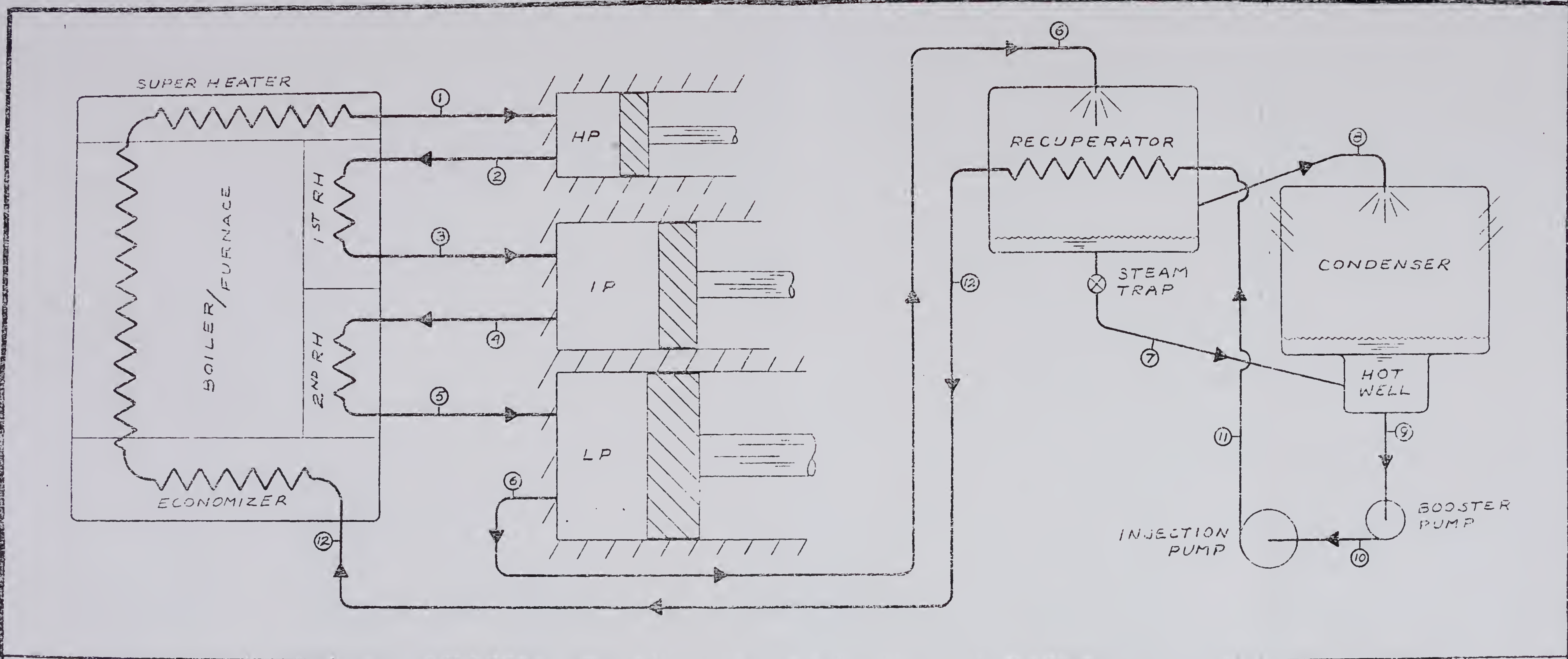
The second law of thermodynamics is that conversion of heat to work is limited by the temperature at which conversion occurs. To apply these thermodynamic principles, the properties of the system being analyzed have to be defined. In the case of the Unitary Steam engine some of these are temperature, pressure, internal energy, entropy, and enthalpy. The ideal gas law ($pv = RT$) as related to an ideal gas mixture such as superheated or saturated water vapor was also used in the calculations. Those and other supportive design calculations are included in Appendix E.

Temperature-Entropy charts, Enthalpy-Entropy (Mollier) charts, as well as the various Keenan and Keyes tables were used to determine the values at the various points of the flow diagram.

The ideal Rankine cycle was used as the standard of reference for performance comparisons of the Unitary Steam Engine cycle efficiencies as determined from energy expended on the fluid. The T-s diagram, included in Appendix E, as developed in conjunction with the thermodynamic calculations was specific to the Unitary Steam Engine.

3.1.3 Mass and Energy Balance

After specific values were assigned at the various points and the thermodynamic calculations were completed and confirmed, the Flow Diagram and Mass and Energy Balance, Drawing 00-80-001-B, was developed. The values for mass and energy balances indicated on the drawing are derived from calculations based on steam injection cut-off at 1/8 of stroke on each stage.



		1	2	3	4	5	6	7 △	8 △	9	10	11	12	13	14	15	16
TEMPERATURE	°F	1200	591	1200	592	1200	439	116	116	102	102	109	439				
PRESSURE	PSI	2800	375	375	47.3	47.3	3.0	1.5	1.5	1.0	250	2800	2800				
ENTHALPY	Btu/lbm	1579.3	1304.0	1631.7	1329.2	1638.7	1260.0	83.7	1111.7	69.7	70.4	78.1	420.8				
ENTROPY	Btu/lbm°R	1.5938	1.5938	1.8399	1.8399	2.0715	2.0715	0.1571	1.9438	0.1326	0.1327	0.1455	0.6070				
SPECIFIC VOLUME	ft³/lbm	0.3268	1.5663	2.6112	13.1828	20.9324	299.5	0.01619	227.7	0.01614	0.01613	0.01616	0.0190				
MASS/CYCLE	lbm/CYC	0.002355	0.002355	0.002355	0.002355	0.002355	0.002355	0.000445	0.001910	0.002355	0.002355	0.002355	0.002355				
ENTHALPY/CYCLE	Btu/CYC	3.7193	3.0709	3.8427	3.1303	3.8591	2.9673	0.0372	2.1233	0.1641	0.1658	0.1839	0.9910				

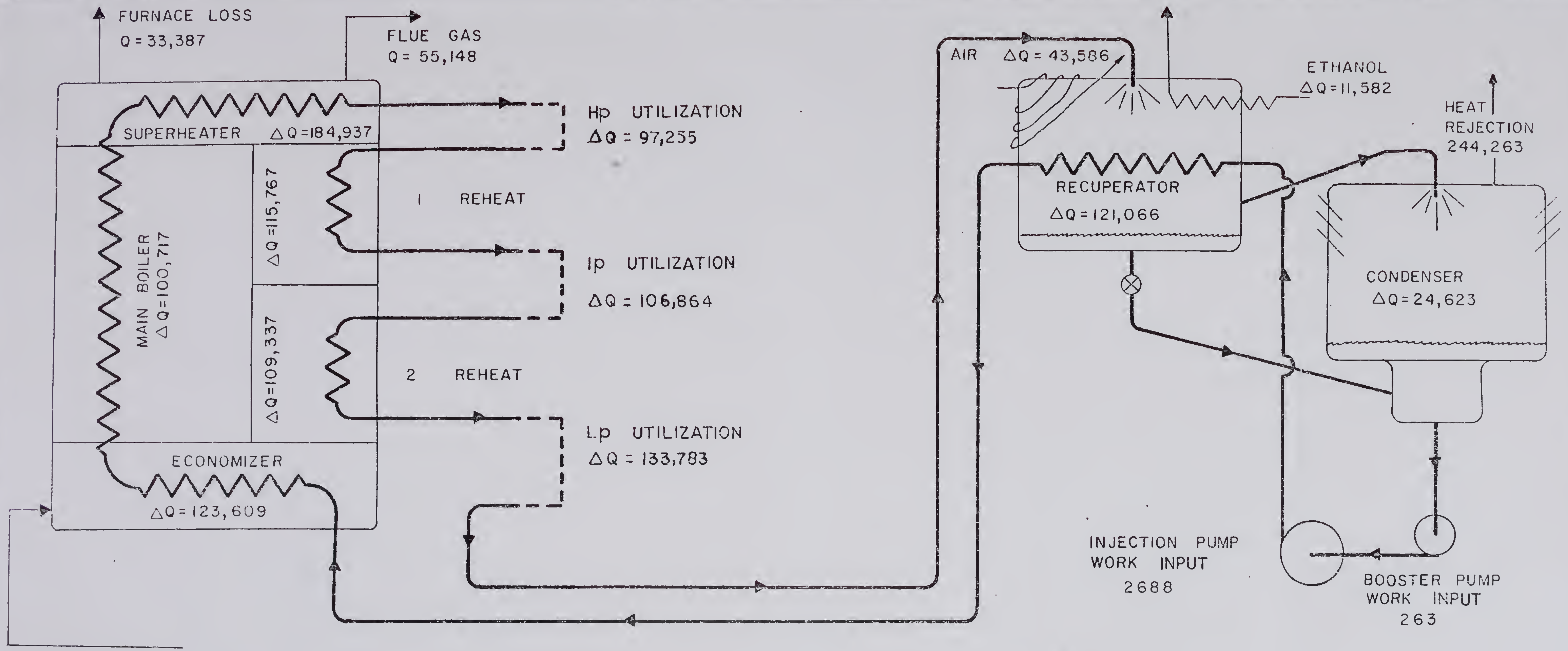
FLOW DIAGRAM AND MATERIAL BALANCE — FOR 1/8 CUT-OFF : HP STAGE

MULTITECH, INC.
Butte, Mt.
DATE 8/14/84
PROJECT NO.
EXHIBIT NO.

MULTITECH FOR COZBY ENTERPRISES
P.O. BOX 4078
BUTTE, MT
P.O. BOX 700
ANACONDA, MT
UNITARY STEAM ENGINE, Project H-331[illegible]-1A, DNRC RAE-84-1036
FLOW DIAGRAM AND MASS AND ENERGY BALANCE (1/8 cut-off)
Scale
00-80-001-B
Rev. △

DESIGNED J.R.K. Cozby
DRAWN R. FULLMER
CHECKED
APPROVED
APPROVED

△ MASS, ENTHALPY on ⑦, ⑧ 10/31/8
△



ETHANOL INPUT
Q= 667,734

ETHANOL PREHEAT
Q=11,582

AIR PREHEAT
Q=43,586

NOTE: ALL FIGURES ARE IN BTU/HOUR

MULTITECH FOR COZBY ENTERPRISES
P.O. BOX 4073
BUTTE, MT
P.O. BOX 700
ANACONDA, MT

UNITARY STEAM ENGINE, Project H-3314-1A, DNRC RAE-84-1048

HEAT BALANCE
DIAGRAM

Scale
00-80-004-B

Rev. △

DESIGNED A. MILLER
DRAWN MJM / KC
CHECKED
APPROVED
APPROVED

The Heat Balance Diagram, Drawing 00-80-004-B, depicts energy balance around the Engine components. These calculations were based on steam injection cut-off at 1/8 of stroke on each stage as previously determined on the Flow Diagram.

Selection of 1/8 of stroke cut-off for calculation purposes represents a maximum efficiency at a minimal operational condition of the Engine. This operating point does not represent the highest horsepower output of the Engine or maximum steam flows.

3.2 COMPONENT DESCRIPTIONS

The Unitary Steam Engine is considered in this report as four separate subsystems. These are the expander, steam generator, condenser, and auxiliaries. See Drawings 00-10-001-D and 00-10-002-D for the spatial relations of these components. Those drawings and others showing specific component parts and subassemblies are listed in Appendix F.

The Engine's expander is where the steam acts to do useful work. The expander includes the cylinder and piston assemblies, crankshaft, crankcase, valves, and valve operators. The expander, sometimes referred to in literature as an engine, is internally lubricated in the same manner as internal combustion engines with oil pumped in a pressurized flow to all areas of potential friction (except valve faces). This prototype will be lubricated with grade SF-CD motor oil.

The steam generator produces steam for the expander's use and sometimes is identified in literature as a boiler; however, it is an integrated unit which combines the functions of recuperator, economizer, boiler, superheater, and reheaters in a mechanical unity. The recuperator, sometimes referred to in literature as a recuperator and sometimes as a regenerator, is that passage of the steam generator where heat is recovered by using exhaust steam to preheat feedwater enroute to the boiler. The recuperator also preheats fuel and air enroute to the burner. The economizer is that passage of the steam generator where furnace exhaust further preheats boiler feedwater.

The boiler is that section of tubes within the steam generator's furnace where water changes phase and becomes steam. Steam generated in the boiler tubes is directed to the superheater, which is that section of tubes in the furnace where extra heat is added to make the steam superheated. The reheaters are those tubes where heat is again added to the steam which was previously expanded in the cylinders. The furnace is that part of the steam generator where fuel combustion takes place. The boiler, superheater, and reheaters are located in the furnace.

The condenser is the part of the engine where expanded steam is cooled. The cooled steam condenses and flows into a reservoir called the hotwell. The hotwell is attached to the condenser. A vacuum pump on the hotwell expels any air which has entered the system so no air is entrained in the steam flow. The vacuum pump could also evacuate the crankcase and valve operator section. In normal operation, vacuum will be maintained by the reduced volume of the water as the steam condenses, but in case of leakage of high pressure steam to the condenser or greatly increased steam delivery to the condenser, the vacuum pump can maintain low back pressure for the Lp stage pistons.

Auxiliaries are the items added on to complete the assembly of the engine. Auxiliaries include an alternator, battery, and a power inverter to provide control power and an electronic ignition system. A starter motor will initiate rotation. Control auxiliaries are the solenoid valves on the water lines and the control panel with its gauges, meters, monitors, and switches. An oil cooler will control the lubricating oil temperature. Other auxiliaries purchased for the Engine are the steam trap on the recuperator for control of condensate flow, the water booster pump to provide pressure head to the injector, the fan to provide air flow through the condenser, the fuel pump, and blowers to provide proper furnace operation.

The controller system, composed of the liquid level controller and ideally furnace heat and pressure controllers, maintains the balance of the separate steam generator functions and provides for safety control of the furnace. The liquid level controller maintains a supply of water in the boiler and a supply of steam in the superheater. The pressure controller would operate air and fuel mixtures and selects burner operation to make the steam generator responsive to differing load demands. Should a malfunction occur in the system, the controller system will shut the furnace off.

3.2.1 Drawing Index, Part Numbers, and Bill of Materials

The simplified drawing log as included in Appendix F encompasses the drawings which illustrate the various aspects of the Unitary Steam Engine. Those drawings marked with an asterisk are key to visualizing and understanding the Engine. The drawing log with complete drawing number is also reprinted following that simplified drawing log.

Individual component part numbers are listed in a reference following the drawing log. Those part numbers correlate to the item numbers given in the U.S. Patent, Appendix A.

Bill of materials and estimate work sheets follow the part number lists. These detail the items, quantities, and descriptions as referenced on the drawings. They provide sufficient detail to order the necessary parts and materials for fabrication of the Unitary Steam Engine.

3.2.2 Operating Parameters

A major operating parameter of the expander is to provide a maximum crankshaft speed of 2,500 rpm. This must be attainable with minimum vibration and cyclic disruption throughout the entire speed range. The cross arm movements and associated pistons must oscillate in harmony with the crankshaft's rotation.

The valves, followers, and cam mechanism must functionally adjust steam flows with various degrees of opening timed to crankshaft rotation.

The steam generator must provide sufficient steam to the expander for operation of the engine at all demand levels. This steam is to be delivered at a nominal 2,800 psia and 1,200°F. Requisite to such a design parameter is sufficient heat transfer surface area to absorb heat for steam generation and then superheating the resulting steam. The furnace must be capable of delivering the necessary heat as required and on demand.

The shell-in-shell construction of the steam generator produces a synergistic effect in its layers of heat scavenging. The feedwater initially gains heat from the exhaust steam in the recuperator. Incoming air passing between furnace exhaust and the recuperator also gains heat. Feedwater and air are further preheated by furnace exhaust in the economizer. The preheating thus accomplished promotes steady-state furnace conditions, so that steam delivery will be 2,800 psia and 1,200^{o}F.

The expander cylinders contained and warmed by the furnace exhaust assist in stabilizing the operation of the furnace and expander.

The condenser must provide enough heat rejection capacity so that exhaust steam will condense. The hotwell must hold enough water for continued operation of the engine.

The operating parameters of the auxiliaries are dictated by the requirements of the subassemblies of which they are a part.

3.2.3 Control and Loading Parameters

In designing the engine, an overview of the expected output of the prototype was necessary for establishing design parameters. The interaction of the moving parts is critical, and has been designed for precise operation to enhance system efficiency. Bearing assembly and clearance tolerances are critical to achieve a balance between excessive friction and excessive vibration, and have been selected according to manufacturers' and industry standards.

In operation, the engine's output will be controlled by four systems: (1) the throttle which governs the steam directed to the expander, (2) the cam mechanism which adjusts the expander's valving, (3) the engine brake which provides an override to normal cam mechanism operation, and (4) the controllers which provide regulation of the steam generator. Normally, output is to be determined by means of Hp stage injection cut-off selection, but the injection steam can be limited or increased on demand by means of the throttle. The throttle also has the capacity to direct full pressure steam to the Ip stage which will substantially increase output. The controllers govern output of the steam generator by balancing water level within the boiler, pressure developed by the steam, and heat delivered by the furnace.

The condenser's output is controlled by a variable-speed fan drive with proportional control.

Engine operation is controlled and monitored by means of the instrumentation detailed in the following list:

CONTROL PANEL INSTRUMENTS AND CONTROLS

- Fuel Pump Switch
- Keyed Ignition Switch
- Starter Button
- Manual Blower Switch
- High Water Level Relay with Light (Water Injector Pump deactivated)
- Low Water Level Relay with Light (Water Injector Pump activated)
- Minimum Water Level Relay with Light* and Warning Buzzer* (Fuel Cut-off)
- Vacuum Pressure Relay* with Digital Read-Out and a "PUMP ON" Light
- Pressure Responsive Process Controllers* with Digital Read-Out, Two Set Points, and High/Low Indicating Lights
- Temperature Controllers* for Fuel Cut-off with Light and Warning Buzzer
- Magnetic Tachometer with Digital Read-Out
- Temperature Monitoring Switches* and Meters*
  - Superheater Wall Temperature
  - First Reheater Wall Temperature
  - Second Reheater Wall Temperature
  - Front of Furnace Temperature
  - Back of Furnace Temperature
  - Exhaust Steam Temperature
  - High Temperature Section of Furnace
  - Hotwell Water Temperature
  - Water in Steam Trap Temperature
  - Water Temperature at the End of Recuperation

- Water Temperature at the End of First Economizer Pass
- Water Temperature at the End of Second Economizer Pass
- Combustion Exhaust Gas Temperature Entering the Economizer
- Combustion Exhaust Gas Temperature Leaving the Economizer
- Combustion Exhaust Gas Temperature from the Stacks
- Fuel Temperature after Preheating
- Air Temperature at the End of Recuperator
- Air Temperature at the Venturi into the Burner
- First Stage Exhaust Temperature
- Second Stage Exhaust Temperature

- Oil Pressure Gauge on Journal Line

- Oil Pressure Gauge on Spray Lines

- Oil Temperature Gauge for Sump Heat

- Oil Temperature Gauge for After Cooling of Oil

- Fuel Pressure Gauge on Burner Line

- Fuel Pressure Gauge on Preheat Line*

- Ammeter*

- Final Exhaust Steam Pressure Gauge

- Second Receiver Pressure Gauge*

- First Receiver Pressure Gauge*

- Blower Air Pressure Gauge

- Furnace Pressure Gauge

- Exhaust Pressure Gauge

OTHER INSTRUMENTS AND CONTROLS

- Manometer for Pressure and Velocity

- Electrical Test Equipment

- Hotwell Water Level Gauge (Sight Tube)

- Fuel Level Gauge (Sight Tube)

- Fifty-five (55) Gallon Graduated Cylinder with Cover (for Fuel Usage Measurement)

* Items desired but not included in this Engine prototype.

3.2.4 Construction Sequence

The engine was fabricated and assembled according to the following sequence of events:

Support Frame

The support frame was built first as a foundation for assembly of the Engine. Subassembly stages of work took place at the same time.

Expander

To construct the expander subassembly, first the expander subframe, Lp cylinders, Ip cylinders, Hp cylinders, water injector cylinders, crankcase walls, furnace cover plate, mid plate, flywheel cover plate, and valve operator section cover were fabricated. The crankshaft was ordered through a subcontract, and to alleviate delays in future assembly, a temporary alignment shaft was fabricated. Once these items were completed they were assembled into a skeleton assembly.

The connecting rods, cross members, cross guide assemblies, and the Ip/Lp piston/rod assemblies were fabricated. Those individual items were assembled into the skeleton with the crankshaft.

The Hp pistons, water injector plungers, head assemblies, Lp valve assemblies, Ip valve assemblies, Hp valve assemblies, cam shaft sleeves, cam follower plates, centrifugal valve advance, push/pull rods and rocker arms and the engine brake assembly were fabricated and individually assembled into the skeleton as they were constructed.

The final steps to complete expander assembly was the installation of the internal lubrication system and oil cooler, the steam connection provisions, and the final shrouding and insulation.

Steam Generator

To build the steam generator, the steam generator subframe and support structure was constructed and mounted on the support frame. The shells, end plates, and internal braces were fabricated and assembled with the applicable internal insulation. The tubing coils were fabricated and inserted in the shell assembly. The fuel lines and burner assemblies were then installed. The controller/steam separator was constructed and installed. The throttle was constructed and installed, and all connections made. The transition piece was constructed, fitted, and mounted. The steam trap, all exterior insulation, and shrouding were installed.

Condenser

To construct the condenser subassembly, the hotwell with its mounting brackets was fabricated and installed on the support frame. The vacuum pump was constructed, tested, and installed. The condenser (an industrial finned tube radiator adapted for use in this prototype) was located, refurbished, installed, and connected.

Final Assembly

To complete the engine, those auxiliaries which were not already incorporated were mounted and connected. The condenser fan was installed. The alternator, batteries, and power inverter were mounted. The ignition system was installed and connected. The water booster pump with its pressure relief valves and the fuel pump were installed. The flywheel and the starter motor were installed. The blower was mounted, and the exhaust stacks constructed and installed. The tachometer was installed. Solenoid valves were installed on the water lines and vacuum pump. The control panel was assembled and mounted, and all gauges, meters, monitors, and switches were connected.

For chronological progress see Appendix D, Chronological Test Report/Weekly Progress Reports.

The foregoing construction sequence is outlined in the following Work Plan which was developed prior to the start of construction. Pertinent related work is also mentioned in that Work Plan.

WORK PLAN

- Obtain quotations on crankshaft and miscellaneous steel material.
- Order crankshaft.
- Obtain facilities and equipment for fabrication and assembly location.
- Obtain support frame, expander subframe, and miscellaneous materials.
- Fabricate crankshaft bearing housings - furnace side cover plate, mid plate, and flywheel side cover plate.
- Fabricate
  - Expander subframe
  - Lp cylinders
  - Ip cylinders
  - Hp cylinders
  - Water injector cylinders
  - Crankcase walls
  - Valve operator section cover
  - Hoist frame for assembly
  - Other associated items that assemble with the above items and are more timely fabricated at this step.
- Assembly of crankshaft, cylinders, walls, and cover plates into a skeleton structure.
- Align bearings for crankshaft.
- Order material for internal reciprocating members, head and valve assemblies, cam assemblies, pistons, engine brake, miscellaneous fasteners, and assembly materials.
- Fabricate
  - Connecting rods
  - Cross members
  - Cross guide assemblies
  - Ip piston/rod assemblies
  - Lp piston/rod assemblies
- Assemble these items into the skeleton structure.
- Rotate by hand the skeleton assembly to check clearances, tolerances, and operational sequence of the unit.
- Order oil pump, oil cooling tubing, shrouding material, insulation, and engine steam connectors.
- Fabricate and assemble the following items into the skeleton structure:
  - Hp piston/rod assemblies
  - Water injector plungers
  - Head assemblies

  - Lp valve assemblies
  - Ip valve assemblies
  - Hp valve assemblies
  - Cam shaft sleeves
  - Cam follower plates
  - Centrifugal valve advance
  - Push/pull rods and rocker arms
  - Engine brake assembly

- Tolerance and clearance checks and measurements conducted during this assembly process insure that operational clearances are maintained and that the engine can be rotated by hand as the assembly progresses. This essentially completes the assembly of the expander and the following ordering, fabrication, and assembly will encompass the steam generator and condenser and their incorporation into the Unitary Steam Engine.

- Order

  - Steam generator subframe and support materials
  - Steam tubing
  - Steam connectors
  - Hotwells for instrumentation temperature and pressure probes
  - Shell material
  - Burner assembly materials
  - Pressure relief head
  - Separator materials
  - Steam trap
  - Shrouding material
  - Insulation

- Fabricate

  - Steam generator subframe
  - Basic shell fabrication
  - Superheater and reheater tubes

- Assemble and fit superheater and reheater tubes to basic steam generator.

- Continue fabrication of steam generator tubing and shell inner materials including recuperator, while fitting the assembly together in a continuous manner. Insert burner assemblies to ensure clearances are maintained.

- Preliminary hydrostatic pressure test before additional assembly to ensure internal tubes and connectors will withstand the operating pressures. Checking during this time allows easier access for any modifications or repair.

- Complete final shrouding and insulation of steam generator.

- Fabricate separator, throttle, and transition piece.

- Assemble separator/controller, throttle, and steam trap. Attach to steam generator.

- Order

  - Condenser with fan
  - Material for hotwell

- Material for vacuum pump

- Order instrumentation and accessories for the control panel.

- Order

  - Pulleys
  - Alternator
  - Batteries
  - Inverter
  - Electronic ignition system
  - Water booster pump
  - Hydraulic pump, motor, proportional control
  - Fuel pump
  - Pressure relief valves
  - Flywheel
  - Starter
  - Blower, blower motor, motor control
  - Exhaust stack material
  - Solenoids and solenoid valves
  - Control panel material
  - Wire

- Fabricate

  - Hotwell
  - Vacuum Pump

- Assemble

  - Vacuum pump
  - Condenser and fan

- Interconnecting tubing from the recuperator to the condenser to complete the interfaces between the major equipment items.

- The basic Unitary Steam Engine has now been assembled. The following auxiliaries modified or fabricated for incorporation.

  - Alternator
  - Starter/flywheel
  - Water booster pump
  - Fuel pump
  - Interconnecting fuel and water piping including valves
  - Blower
  - Inverter
  - Batteries
  - Interconnecting wiring
  - Exhaust stacks
  - Control panel
  - Associated controls including gauges, monitors, switches, etc.

- The entire engine assembly rotated by hand to confirm sequence of operations and allow minor modifications as required.

- Fill with water, lubricating oil, hydraulic oil, and fuel preparatory to testing.

3.2.5 Testing

As the Engine was built, each subassembly was inspected and measured for fabrication tolerance control and hand operated to assure proper motion and action. The following testing was proposed as appropriate during and after assembly:

- The Engine will be subjected to pressure testing, compressed air testing, and vacuum testing.

- Valve motion effort will be measured, and valve and valve operator action will be tested to confirm timing.

- Leverage checks will be accomplished during fabrication and subassembly to assure spring rates are adequate for valve displacement.

- Accepted measurement techniques will be used during assembly to provide internal clearances, operating clearances, and fastening tolerances for the engine subassemblies.

- The crankshaft was subjected to a visual inspection at the manufacturer's facility. A balancing procedure was also accomplished to insure that this main component of the engine is acceptable for prototype demonstration.

- Other fabricated parts and assemblies such as the connecting rods, cross arms, cams, valves, etc., were visually inspected to insure that there were no obvious machining errors such as nonrelieved fillets, extraneous cuts, or other such defects that could concentrate stress or strain and that might result in eventual failure.

- Some of these components, fabricated under major machining operations, may be tested by a surface dye penetrant check.

- Oil pressure and distribution will be tested, including checks to insure that sufficient lubricant is delivered to all moving parts for proper operation. Parts to be lubricated include the main bearings and the crankshaft, which is internally pressurized to deliver oil to its throw journals and from the throw journals through the connecting rods to the wrist pins. The valve operator system, including cams, cam followers, push/pull rods, and rockers will be oiled, as will the engine brake assembly, the oil pump drive, the cross guides, and the Hp, Ip, and Lp cylinders.

- Checks will be made to insure that the oil is being properly contained by the seals and piston rings.
- The valves will be tested to confirm positive sealing; the valves' water lubrication system will be tested to insure free movement and no galling.
- The recuperator, economizer, boiler, superheater, and reheater tubes will be subjected to hydrostatic pressure testing.
- The boiler tubes will be checked for flow.
- The gas passages for air, steam, and furnace exhaust will also be checked for flow.
- The furnace will be tested for flame pattern, heat delivery, and temperatures.
- The controllers will be calibrated and tested to insure safety and performance characteristics.
- The finished assembly will be monitored to determine its fuel and air input, quantity and quality of steam delivered, emissions, and efficiency.
- The condenser and the hotwell will be pressure tested to assure gas-tight operation under all load conditions.

Performance testing will be conducted according to the means and methods discussed in Section 4.0, Performance Monitoring.

3.3 ASSUMPTIONS AND CALCULATIONS

This section deals with the data developed to support and substantiate the Unitary Steam Engine design. Subassemblies are treated in separate subsections in this section to provide clarity and organization. References and engineering worksheets are appended to support the assumptions and calculations. The Bibliography included in Appendix G includes those appended references in an alphabetical order as well as other references used in design or procurement. Reference is also made to the Supportive Design and Calculations included in Appendix E and the Drawings which are listed in Appendix F.

3.3.1 Bearings and Seals

The Unitary Steam Engine uses ball bearings for its main crankshaft bearings. The connecting rods ride on journal bearings, and there are four crankshaft throw journals and four wrist pin journals. An engine brake bearing is required for manual valve control. Three seals are necessary on the crankshaft to ensure proper lubrication and separation of crankcase lubricant and contaminants. The water injectors and all valve stems require packings to prevent leakage. All metal to metal contacts require sealing with gasket compound.

Roller bearings for the crankshaft throws were rejected because use of roller bearings on the throws would interfere with lubrication of the wrist pins. Roller bearings would also add unnecessary mass and restrict the speed of the engine because of the split races. Furthermore, journal bearings have been used successfully in this application for many years in other engines of similar speed and output.

Specifications were detailed from CR Handbook of Seals, Chesterton Mechanical Packings, FAG Standard Program Catalogue 41500/2ED, SKF Product Catalog, and Detroit Diesel's Shop Manual for 71 T Series Engines. Manufacturer's recommendations were adhered to in selecting bearings and seals.

3.3.2 Steam Generator

The output of the steam generator has been calculated on the basis of steam required for 1/8 cutoff operation of the expander. Steam requirements were also projected for maximum horsepower requirements. The calculations indicate excess capacity, so the steam generator is considered acceptable as designed for prototype usage.

Temperatures of combustion and combustion gases and the consequent furnace temperatures are based upon estimates developed from engineering handbook data. The figures thus obtained were used to develop the calculations for heat transfer. That heat transfer dictates steam generation capacity. The computed steam generation capacity was compared to published data of similar steam generators and was deemed reasonable.

References include Chemical Engineers' Handbook, pp. 9.41-9.43, 10.21-10.22, Fundamentals of Boiler Efficiency, Handbook of Engineering Fundamentals, pp. 8.73-8.78, Kent's Mechanical Engineers' Handbook, Power Volume pp. 7.12-7.40, Marks' Standard Handbook for Mechanical Engineers, 8th Edition, pp. 9.7-9.34, Oil Burners, Principles of Heat Transfer, Chapters 8 and 11, and Steam/Its Generation and Use, pp. 4.9-4.12; 6.1-6.11.

3.3.3 Cams

The cams to operate the engine's slide valves were designed to operate directly on the engine's crankshaft, and will be high-speed and fast-operating. The cams have been designed to deliver minimum shock and vibration in consideration of the mass and inertia factors of acceleration and deceleration in the valve train.

Initial cam design work was based on Machinery's Handbook, pp. 712-729, and Technical Drawing, pp. 605-608. Mechanical Engineer's Handbook, pp. 884-886 as well as the Encyclopedia Britannica, Vol. 4, pp. 675-676 were used to substantiate theory and calculations. Harmonic, constant velocity, and constant acceleration motions were all rejected due to the stringent nature of the cam requirements.

Final design is based on cycloidal cam motion as described in Kinematics and Dynamics of Machines, pp. 205-208.

3.3.4 Condenser

Condenser calculations were based on heat rejection capacity necessary for the steam to condense and indicate that the finned tube radiator specified will perform adequately as a condenser for this prototype. It will condense all of the exhaust steam at 1/8 and 1/4 cut-off, and it should condense most of the exhaust steam at 1/2 cut-off. This will be sufficient for proof of concept operation and a considerable amount of operational testing. Heat rejection is affected by such variables as fin design, cooling air volume, cooling air velocity, fan efficiency, ambient conditions, and internal operating pressure.

Calculations were based on data published by Onan for its radiator applications. These data were compared to figures of heat rejection for the engine that the specified radiator serves. This information was further compared to published data concerning heat rejection rates and capacities for condensers developed in the 1970's.

References include Installation Information for Onan Liquid-Cooled Electric Generating Sets, pp. 8, 9, 30-34 and An Assessment of the Technology of Rankine Engines for Automobiles, pp. 4, 18-21, 25, 27, 30, 39, 40, and 46.

3.3.5 Connecting Rods

The connecting rods, which transmit the force developed by the pistons to the crankshaft, have been designed to be of sufficient strength to withstand the stresses of extreme pressure and shock loading to which they will be subjected, and yet be as light as possible to avoid negative effects of excessive mass in the reciprocating parts.

Initial design work was based upon the assumption that connecting rods from a 6-inch stroke diesel engine would be strong enough to use in the engine, however, analysis of the connecting rods used in a two-cycle and four-cycle diesel engine showed the necessity of designing connecting rods of greater strength.

The selected connecting rod design is sufficient to withstand all of the stresses and loading that the prototype is expected to develop. The material specified, Astralloy V, is noted for its toughness, strength,and long life in similar applications. The two- piece, split design allows the loading from the work developed by the pistons to be transmitted to the crankshaft via a path of integral material, whether on 0-180° stroke or 180-360° stroke. The strength of the bolts used to assemble the connecting rod exceeds the centrifugal loading delivered by the rotation of the crankshaft.

3.3.6 Crankshaft

Maximum theoretical output of the engine is 713 horsepower and 1500 foot-pounds of torque, therefore, the crankshaft has been designed to accept and deliver such a load. The maximum rated speed of the engine is 2,500 rpm based upon a maximum average piston speed of 2,500 feet per minute on a 6-inch stroke. The crankshaft design includes provision for balance of the dynamic loading from the work developed by the pistons. Finish dimensions were chosen for use of commercially available bearings and seals.

The 2.75-inch diameter of the driveshaft will be capable of delivering 1,368 horsepower. Critical speed was computed at the most extreme loading and was found acceptable pending testing of the prototype. The design criteria includes dynamic balancing to 3,000 rpm. The crankshaft has three throws: Nos. 1 and 3 located at 0^o, and No. 2, a double throw opposed to 1 and 3, located at 180^o. Nos. 1 and 3 throws, with one connecting rod each, connect to one of the engine's cross arms with its associated pistons. No. 2 throw has two connecting rods which connect to the other cross arm and its associated pistons. This arrangement minimizes unbalanced loadings on the crankshaft.

References include Mechanical Engineers' Handbook, pp. 517, 932-33, 1333, 1455, and 1517; Kent's Mechanical Engineers' Handbook, Power Volume, pp. 14.65 and Machinery's Handbook, 19th Edition, pp. 351, 352, 451, 2030.

3.3.7 Flow Rates

Steam flow rates, which affect porting for the engine's valves are in accordance with industry standards and are established as 15,000 ft/min. maximum for injection and 9,000 ft/min. maximum for exhaust. Flow within the steam generator tubing has also been limited to 15,000 ft/min. maximum.

References include Audels Engineers and Mechanics Guide, Vol. 4, p. 1693; Mechanical Engineer's Handbook, p. 1223; and Marks' Standard Handbook for Mechanical Engineers, 8th Edition, p. 938.

3.3.8 Heat

To enhance the adiabatic characteristics of the Unitary Steam Engine, the cylinders are exposed to furnace exhaust to prevent cylinder wall condensation and to promote steady-state conditions for steam expansion. Use of ceramic pistons retards heat transfer to the piston rod and crankcase interior. The crankcase is evacuated to the same pressure as the hotwell to further retard heat transfer into the crankcase. Because of the high temperatures involved, cooling air is directed over the crankcase to keep the lubricant at optimum temperature. Hot and cool areas are maintained in a discrete condition by means of appropriate shrouding and insulation.

Although the use of ceramics will have some effect on start-up and warm-up of the engine, the effect is expected to be negligible since the coefficients of thermal expansion are similar for the ceramic of the pistons and the metal of the cylinders and the piston rods.

Heat transfer calculations for the steam generator are specific for the recuperator, economizer, boiler, superheater, and reheaters. These calculations show sufficient heat transfer capacity to generate steam adequate to power the engine.

Heat values for the condenser and the hotwell are specific for that system's thermodynamics.

References include Principles of Heat Transfer, Chapters 8 and 11, and Steam/Its Generation and Use, pp. 10.21-10.22.

3.3.9 Horsepower

The Engine's output in horsepower is calculated on the basis of computed steam consumption and computed heat investment per pound of steam. The indicated horsepower of 713.3 at full bypass is a gross output figure. Actual net system output will vary according to a complex mix of factors which include mechanical efficiency (friction), power necessary for peripherals and components, effective effort developed during high speed operation, degree of theoretical heat transfer attained, and actual operational temperatures attained.

References include Mechanical Engineers' Handbook, pp. 1194-1196; Kent's Mechanical Engineers' Handbook, Power Volume, pp. 8.102-8.110; Marks' Standard Handbook for Mechanical Engineers, pp. 9.36-9.38; and Machinery's Handbook, 21st Edition, p. 328.

3.3.10 Instantaneous Piston Speed

Instantaneous piston speed is a necessary calculation to determine proper steam ports and was determined according to the following formula from Kinematics and Dynamics of Machines, p.173.

$$V^{x}_{c} = -Rw_{2}(\sin\theta + \frac{1 \sin 2\theta}{2n})$$

Average piston speed is limited to 2500 feet per minute in accordance with past practice.

Other references include Kent's Mechanical Engineers' Handbook, Power Volume, pp. 14.69-14.71.

3.3.11 Mass of Reciprocating Parts

The mass of reciprocating parts includes the weights of all pistons, piston rods, cross arm assemblies, wrist pins, and connecting rods with assembly bolts and fasteners. Weights of materials were taken from Ryerson's Products in Stock Handbook.

3.3.12 Pistons

To achieve the desired high efficiency, the triple expansion Unitary Steam Engine uses three sizes of pistons.

The high pressure (Hp) piston is the smallest in diameter, 1.0625-inch, and is of plunger configuration with a stuffing box packing to seal against gas leakage. The intermediate pressure (Ip) piston, 2.125-inch diameter, is joined to the low pressure (Lp) piston, 6.000-inch diameter, by a piston rod. Both the Ip and the Lp pistons are sealed by commercially available rings. For improved thermal properties and reduced reciprocating mass, both the Ip and Lp pistons will be constructed of machinable ceramic.

The Ip and Lp ceramic pistons will be attached to the aluminum piston rod and steel backing plate by threading the inside of each piston and screwing it onto the piston rod. The pistons will be held in place by an application of a high-temperature inorganic cement, such as Sauereisen No. 29 or No. 31, and by lock screws through the face of the piston into the piston rod. The Lp piston will also have a backing plate.

3.3.13 Pressures and Temperatures

To maintain the thermal advantages of dry steam and keep the entropy increase of multiple reheats as low as possible, the initial pressure and temperature of 2,800 psia and 1,200°F with reheat temperatures of 1,200°F have been selected. The pressure/temperature factors cited in the specific calculations for all other state points are computed on the basis of the following formula or read from the Mollier chart or steam tables.

$$P_1V_1^{1.315} = P_2V_2^{1.315} \quad \text{or} \quad V_2 = V_1\ (P_1/P_2)^{.7604}$$

References include Steam Tables, Marks' Standard Handbook for Mechanical Engineers, pp. 4.22-4.31, 9.37; Kent's Mechanical Engineers' Handbook, pp. 4.1-4.44, 8.102-8.105 and Mechanical Engineers' Handbook, pp. 322-335, 1194-1207.

3.3.14 Pumps

To maintain internal lubrication, the engine will have an oil pump driven by the crankshaft. A water booster pump will maintain a pressure head of 250 psi to prevent cavitation in the water injector pump. The primary water injector delivers high pressure feedwater and the secondary water injector circulates boiler water. These injectors are integrated with one cross arm assembly. Fuel delivery will be accomplished by means of an auxiliary fuel pump.

References include Kent's Mechanical Engineers' Handbook, Power Volume, pp. 5.71-5.78, 13.22, 14.68 and 14.69; Machinery's Handbook, 21st Edition, pp. 556-560, 667-675; McMaster-Carr Catalog 90, p. 1063; Chemical Engineering, September 21, 1981, pp. 104-123 and Marks' Standard Handbook for Mechanical Engineers, pp. 14.2-14.12.

3.3.15 Ratios

The rocker arms incorporate a 1.5:1 ratio of arms length to reduce the cam follower movement and thus reduce inertial forces in the cam follower plates. The connecting rod to stroke ratio is 1.75:1. The cylinder displacement ratio is 1:8:64. The steam expansion ratio (R) is a pressure/volume variable. Some R values relative to selected volumetric ratios are as follows:

$V_1 : V_2$	R
1 : 8	15.403
2 : 8	6.191
2.67 : 8	4.244
3 : 8	3.634
4 : 8	2.489

R for the Hp stage is a variable according to injection valve cutoff selected. R for both the Ip and Lp stages is fixed at 15.403 since the valve cutoff for both stages is fixed at 1/8 stroke. R for the engine is the product of the stages.

3.3.16 Receiver/Reheater

The reheaters are receivers interposed between the expander stages. These receivers accept exhaust steam from one stage and hold it while it is being reheated preparatory to injection into the next stage. By design, the No. 1 reheater contains a volume twenty times as great as the displacement of the Hp stage. Likewise, the No. 2 reheater contains a volume twenty times as great as the displacement of the Ip stage.

To achieve the most beneficial thermal balance, the reheaters have been subdivided into multiple tubes. The volume-to-surface areas have been adjusted by means of selecting proper tubing sizes to gain the best heat transfer characteristics.

3.3.17 Recuperation and Regeneration

Recuperation and regeneration are sometimes considered synonymous, but are also sometimes used to differentiate between heat scavenged for preheating water, air, and fuel from exhaust steam and heat scavenged from furnace exhaust. In this report, the terms are considered synonymous because the heat transfer from exhaust steam and furnace exhaust are so intermixed that the differentiation is meaningless.

3.3.18 Steam Consumption; Steam Mass

Steam consumption relates to horsepower output and efficiency of operation. Steam consumption is determined by the formula $C = MN$; where C is consumption in pounds per minute, M is mass of steam ingested per revolution in pounds, and N is revolutions per minute. M is determined by the formula $M=nAL \div 1728v$; where n is number of cylinders, A is area of a cylinder in square inches, L is length of stroke in inches, v is specific volume in cubic feet per pound.

The volumetric displacement of the total Hp stage is equal to one-eighth of the Ip stage so that at 1/8 stroke on the Ip stage, the volume of steam ingested by the Ip stage is equal to the volume of steam being exhausted by the Hp stage. The volumetric displacement of the total Ip stage is equal to one-eighth of the Lp stage so that at 1/8 stroke on the Lp stage, the volume of steam ingested by the Lp stage is equal to the volume of steam being exhausted by the Ip stage. Thus the mass of steam ingested by the Hp stage is expanded and passed to the Ip stage to be expanded and passed to the Lp stage to be expanded and exhausted. The mass of steam introduced into the expander by Hp stage ingestion equals the mass of steam used by each stage and equals the mass of steam exhausted, when the Hp stage injection cutoff remains constant. If the Hp injection is changed, the mass of steam injected in each subsequent state is a dynamic variable reflecting the change in system input.
The Ip and Lp stages will make a relatively gradual adjustment to the Hp change because of their receivers.

The computed steam consumption forms the basis for steam generation calculations. The actual steam consumption fixes actual steam generation demand.

3.3.19 Stress Analysis

Stress analyses have been calculated for the connecting rods, cross members, crankshaft, bearings, steam generator shells, and support frame. All of these parts are found to be well within acceptable limits. Stress on the steam generator tubes has been limited by published pressure and temperature allowances.

3.3.20 Thermal Efficiency

Thermal efficiency (e_t) is the ratio of work delivered to the work potential of the fuel expended. Converting the work delivered (horsepower output) to Btu's and dividing by the Btu value of the fuel consumed results in the thermal efficiency. The formula for computing ideal thermal efficiency for Rankine engines is

$$\begin{gathered}(h_c - h_d) + (h_e - h_f) + (h_g - h_h) - Wp \\ (h_c - h_a) + (h_e - h_d) + (h_g - h_f)\end{gathered}$$

where h_c, h_d, h_e... is enthalpy, and Wp is work of pumping.

Net system efficiency is the product of ideal efficiency, expander efficiency and boiler efficiency. Expander efficiency is projected to be 85 percent. Boiler efficiency is projected to be 95 percent. Net system efficiency of the completed prototype will be based upon measured fuel consumption and output by applying the formula

$$e_t = 254{,}400 \div (\text{bsfc} \times h)$$

where bsfc is brake specific fuel consumption as measured in pounds per brake horsepower/hour, and h is heat of fuel as expressed in Btu per pound.

References include Handbook of Engineering Fundamentals, pp. 8.66-8.84, Kent's Mechanical Engineers' Handbook, Power volume, pp. 4.02-4.06, Mechanical Engineers' handbook, pp. 346-347, 1201-1213, Marks' Standard Handbook for Mechanical Engineers, pp. 4.27, 4.28, Steam Tables and Mollier Chart.

3.3.21 Thermodynamics

Thermodynamics is defined as the study of energy conversion and transfer. The thermodynamics of the engine are discussed more particularly in Section 3.1.2. Those principles were used throughout the assumptions and calculations.

References include those cited in the Sections noted above with special note on Kent's Mechanical Engineers' handbook, Power volume, pp. 3.50-3.53, 3.60-3.63, 4.02-4.37, and Handbook of Engineering Fundamentals pp. 8.63-8.84.

3.3.22 Torque

Torque (Q), the rotational force of the engine, is determined by the formula Q = 5,252 HP ÷ rpm, where Q is torque in foot-pounds, HP is horsepower, and rpm is revolutions per minute. Specific torque values were calculated with the horsepower calculations. A torque of 1,499 ft/lb at full bypass corresponded to the maximum horsepower of 713.3.

References include Machinery's Handbook, 21st Edition, p. 283 and Engineering Handbook, p. 9.

3.3.23 Valves

The synergistic effect of the Unitary Steam Engine is greatly enhanced by the valves. The valves are designed to 1) reduce mass and friction while maintaining maximum structural integrity in consideration of valve train inertia and acceleration/deceleration, 2) separate injection and exhaust steam in consideration of thermal improvement, 3) allow fast operation coupled with precise timing in consideration of steam flow and porting, 4) minimize valve clearance for increased system efficiency, and 5) ensure positive gas seal for leak-proof operation. The valves are built of a low coefficient of friction material and operate on a valve seat made of low coefficient of friction material. The valve and valve seat incorporate a water lubrication system that will not contaminate the steam and will aid the sealing of the valve by fluid film. The valve stems are designed to improve mechanical efficiency by reducing negative work.

References include Machinery's Handbook, 21st Edition, pp. 544-547, Marks' Standard Handbook for Mechanical Engineers, pp. 3.24-3.32, 9.38, Mechanical Engineers' Handbook, pp. 1215-1223, Kent's Mechanical Engineers' Handbook, Power Volume, pp. 8.101-8.102, 8.109, 8.111 and Handbook of Engineering Fundamentals, pp. 8.79 and 8.80.

To correlate the formula given in paragraph 3.3-20, the following addendum is provided:

$$\frac{(h_c - h_d) + (h_e - h_f) + (h_g - h_h) - W_p}{(h_c - h_a) + (h_e - h_d) + (h_g - h_f)}$$ = Ideal Thermal Efficiency, to the flow diagrams 00-80-001-B and 00-80-003-B: h_a = Enthalpy at point 12; h_c at point 1; h_d at point 2; h_e at point 3; h_f at point 4; h_g at point 5; and h_h at point 6. W_p - the enthalpy of point 11 minus that at point 9.

That calculation reduces to: $\frac{948.5 \text{ Btu}}{1,795.7 \text{ Btu}}$ = 52.8% Ideal Thermal Efficiency.

It should be noted that further analysis has shown that the enthalpy at point 12 is somewhat inflated, but that the given value, 420.8, is attainable with the addition of bleeding for feedwater heating at points 2 and 4. Reference regenerative cycle in Mark's 4th edition, pp. 347-348. Such a design change is fairly simple and will be incorporated in future developments. Therefore, an Ideal Thermal Efficiency of 52.8% is accepted as accurately representative.

Past practice has established boiler-furnace efficiencies of 95% to 98%. Reference and DOE Assessment of the Technology of Rankine Engines for Automobiles, pp. 37 and 48. Realizable expander efficiencies for well designed piston engines are 81% and above. Reference Mark's 4th edition, pp. 1204 and Kent's 12th edition, pp. 8-108).

The formula for realizable thermal efficiency for the total system is:

Boiler-Furnace Efficiency X Expander Efficiency X Ideal Thermal Efficiency

The expected realizable thermal efficiency as calculated is approximately 40% to 43%. Such an efficiency is an improvement over present steam engine technology and is competitive with the best internal combustion engine technology.

4.0 PERFORMANCE MONITORING

When the engine had been built and proven operational, its performance was to be assessed in accordance with the data entered in this Section. This information would then provide engineering and analysis background as well as support for the Marketing segment of the business plan used to attract capital for commercial production of the Unitary Steam Engine.

The marketing strategy will depend upon the following:

1. Proof of functionality
2. Fuel diversification/renewable energy
3. Performance characteristics
4. Efficiencies
5. Emissions and
6. Noise abatement.

Since the Engine did not sustain operational status, adequate performance monitoring was impossible. Therefore, the plan contained in this section was not implemented. It is included to detail the necessary monitoring of an operational prototype for the next project.

4.1 MONITORING PLAN

To generate sufficient data to confirm the performance of the Engine, the following monitoring plan has been devised.

BRIEF OUTLINE OF PERFORMANCE MONITORING PROCEDURE

I. Visual/Manual/Function tests of each component as completed
II. Visual/Manual/Function tests of assembled system
III. Function tests of Engine brake
IV. Function tests and limits of throttle
V. 3 2-hr tests at 1/8 cut-off
VI. 2 2-hr tests at 1/4 cut-off
VII. 2 2-hr tests at 3/8 cut-off

VIII. 1 10-hr test at 1/8 cut-off
IX. 2 1-hr tests at maximum power
X. 1 2-hr test at 1/8 cut-off
XI. 4 1-hr tests at nonsteady state
XII. 1 2-hr test using throttle by-pass at various cut-offs

(TOTAL: 34 hours of test runs not counting function tests and torque tests.)

XIII. Torque tests
XIV. Develop information gathered
XV. Evaluate these results
XVI. Summarize performance assessment

4.1.1 Heat Transfer and Thermodynamics

Calculations on the thermodynamic properties will be completed after the Unitary Steam Engine has operated a number of times and the initial modifications to the Engine have been completed. The Engine will be brought up to operating temperature and loaded at 1/8 cut-off where individual pressures, temperatures, flows, and other pertinent data will be collected. That data will then be used in the appropriate formulas for calculations as shown in Appendix E. The following engineering analysis logs in particular will be used as references for the calculations or to confirm selected operating positions:

10-3	Thermo Analysis/Process Schematic
10-4	Steam Consumption Rate Analysis
10-5	Indicated Horsepower
10-8	Booster Pump Calculations
10-17	Ethanol Fuel Requirement and Combustion
10-19	Boiler Heat Transfer
10-20	Recuperator Heat Transfer
10-21	Air Heater and Ethanol Preheat
10-22	Flue Gas Heat Calculation
10-23	Energy Balance
10-27	Condenser Heat Rejection Calculations and
10-29	Instrumentation.

4.1.2 Heat Transfer

To analyze actual transfer of heat, the following data will be monitored and recorded. Numerals in parenthesis at right refer to points on the Mass and Energy Balance, Drawing 00-80-001-B.

- Ethanol Fuel Analysis
- Stack Gas Analysis
- Temperatures of
  - Incoming ambient air
  - Preheater air before combustion
  - Combustion temperature at approximately 6-8 inches from the flame
  - Exhaust at intermediate location
  - Exhaust at exhaust stack
  - Ambient ethanol and
  - Ethanol at point of injection/after preheat
- Water and/or Steam Temperature at
  - Hotwell suction of booster pump (9)
  - After recuperator (12)
  - After economizer (13)
  - After boiler tubes (14)
  - After superheater (1)
  - After HP cylinder (2)
  - After first reheat (3)
  - After Ip cylinder (4)
  - After second reheat (5)
  - After Lp cylinder (6)
  - Condensate to hotwell (7) and
  - Steam to condenser (8)
- Pressure at
  - Hotwell (9)
  - After booster pump (10)
  - After boiler tubes (14)
  - After Hp cylinder (2)
  - After Ip cylinder (4)
  - After Lp cylinder (6) and
  - After blower discharge.

4.1.3 Fuel, Horsepower Output, Efficiency, Emissions

The Engine will be connected to a dynamometer and at the specified 1/8 cut-off, fuel will be volumetrically measured per unit of time. The Engine will have to be in a stable mode of operation at approximately 2,000 rpm and operate in that mode for a period of 15 minutes to provide constant uniformity of fuel-steam-energy conversions.

The brake horsepower will be determined from the dynamometer, which measures the horsepower delivered at the output end of the Engine.

The specific fuel consumption is the ratio of fuel consumed in pounds per horsepower per hour of operation. This calculation will be computed as brake specific fuel consumption. The thermal efficiency of the Engine (ratio of output to input) will also be calculated based on the fuel burned. This brake thermal efficiency can be restated as the ratio of the brake horsepower produced to the potential horsepower in heat units of the fuel consumed. Thermal efficiency calculated in this manner accommodates any other fuel anticipated as it reduces to basic heat units.

Emissions data as measured in the exhaust of the Engine will be analyzed to determine excess combustion air and assist in determining the stability of operation. In addition, this analysis is required to determine potential emission problems of the Engine's exhaust.

Heat rejection in the condenser will be calculated from the previously taken flow and temperature data.

Performance characteristics of the Engine will be objectively judged during the operational phase. These will include such parameters as responsiveness to throttle demand, time periods to reach other Hp cut-off steps, and brake horsepower generated at various throttle/Hp cut-off loadings.

4.2 EQUIPMENT

Monitoring equipment is outlined on pages 69-72 of the Bill of Materials in Appendix F. DNRC's Neotronics Fuel and Efficiency Analyzer was used in conjunction with that monitoring equipment.

4.3 DATA

Test data sheets developed during the initial operational tests are included in Appendix C, Test Data Reports. More extensive test data during longer term duration tests will be entered according to the monitoring record sheets also included in Appendix C.

4.4 CALCULATIONS

The following mathematical exercises will be used to reduce the raw data to statements of performance:

- Ethanol preheat calculation
- Air preheat calculation
- Recuperator feedwater heat gain calculation
- Economizer feedwater heat gain calculation
- Main boiler heat gain calculation
- Superheater heat gain calculation
  - HP stage heat usage
- First reheat gain calculation
  - IP stage heat usage
- Second reheat gain calculation
  - LP stage heat usage
- Percentage of condensate and steam from recuperator
- Condenser heat rejection calculation
- Work added by booster pump and
- Work added by injector pump.

5.0 ECONOMICS

In order to more accurately assess the steps remaining to commercial production, and in order to place a reasonable estimate of the value of this development work, this section presents a preliminary analysis of economic factors. Those factors relate to developing next-stage prototypes, starting limited mass production, manufacturing, selling the end user the product, and some of the projected impacts on the economic status of Montana.

Investment from grants, initial stock sales, and personal contributions form the economic basis for this prototype project. This first operable prototype for proof-of-concept did not generate any funds that could be credited as income. The second and third stage prototypes will require an additional six years of development with estimated total costs of six million dollars. Again, during this period of time there are no funds credited as income.

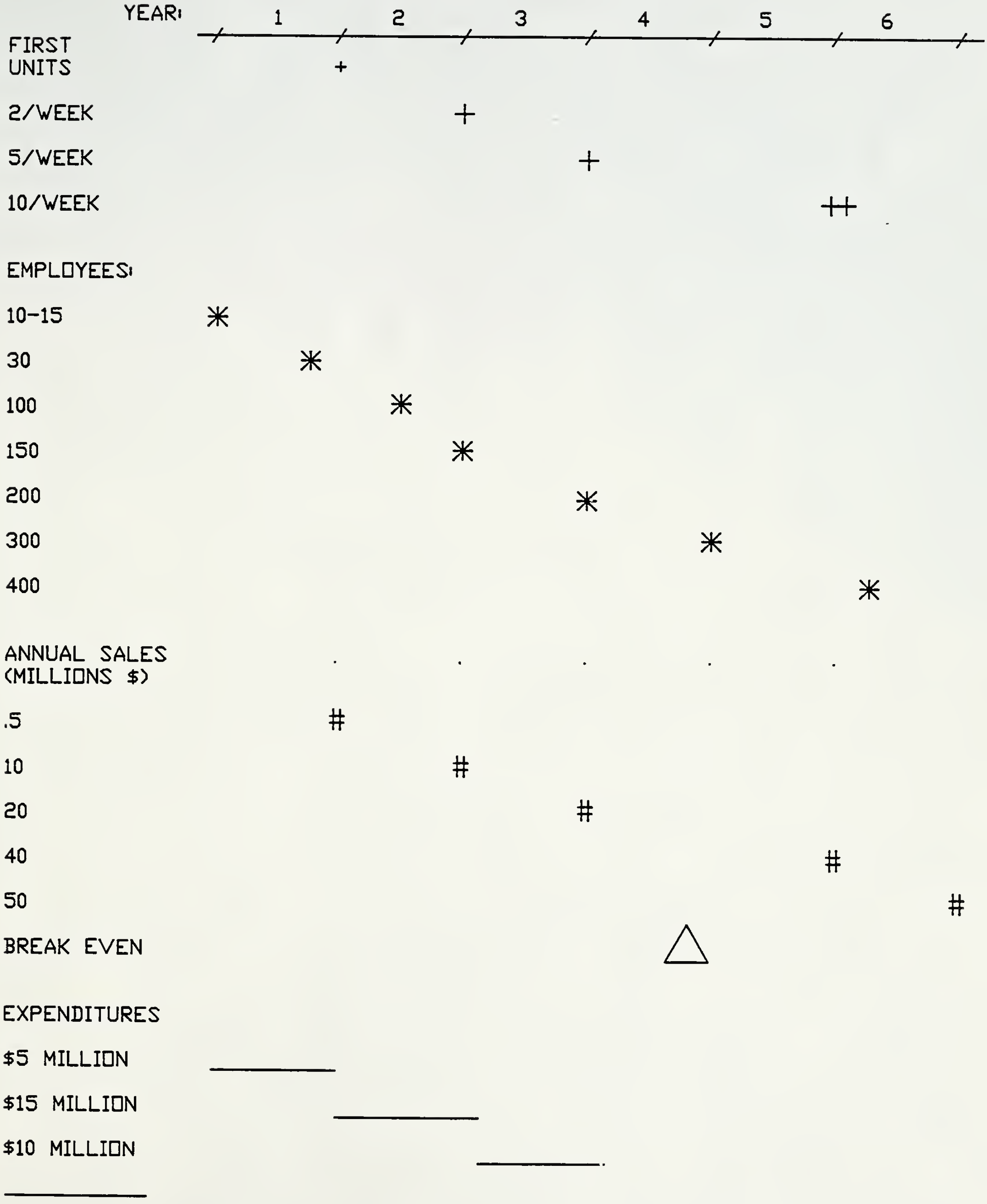
Projected funding requirements of 30 million dollars would then be required to attain small scale limited mass production of a single engine family (1,500-15,000 horsepower) for stationary, locomotive, marine, and co-generation applications.

Figure 5-1 shows the projected production levels, employees, annual sales, investment, and investment break-even point for the initial six years production. This figure does not include the six million dollars required for development prior to the limited mass production runs.

Figure 5-2 shows the projected number of units manufactured, number of employees, and a cumulative investment debt of 30 million dollars. A debt retirement line was then plotted which indicates that a break-even point is reached at the end of four years. That debt retirement line was based on the following percentage factors of the factory price:

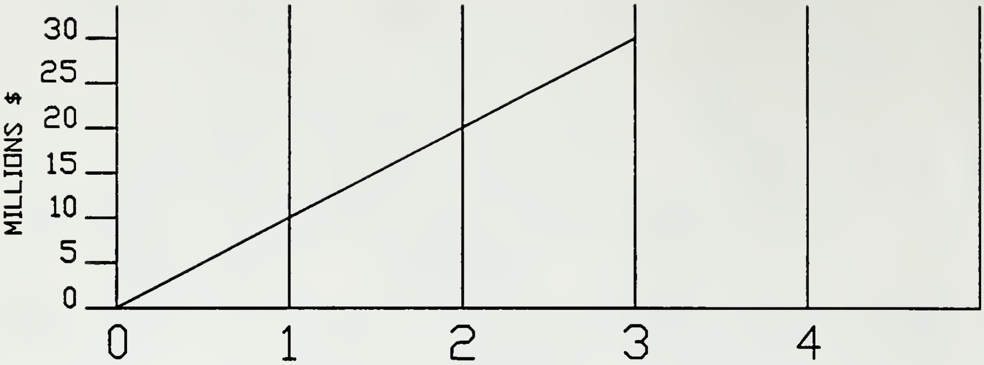
Debt Retirement or Re-investment	21%
Marketing, Commissions, Contingencies	10%
Return on investment	10%
Royalty	6%
Material	23%
Direct Labor	15%
Fringe and overhead	15%
	100%

SIX YEAR ECONOMIC PROJECTION

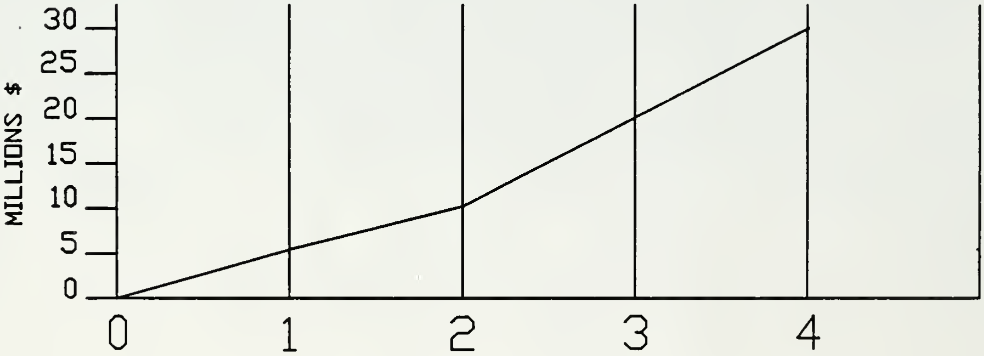


#30 MILLION (FROM INVESTMENTS, GRANTS, LOANS, ETC.)

FIGURE 5-1



CUMULATIVE INVESTMENT DEBT



TOTAL DEBT RETIREMENT

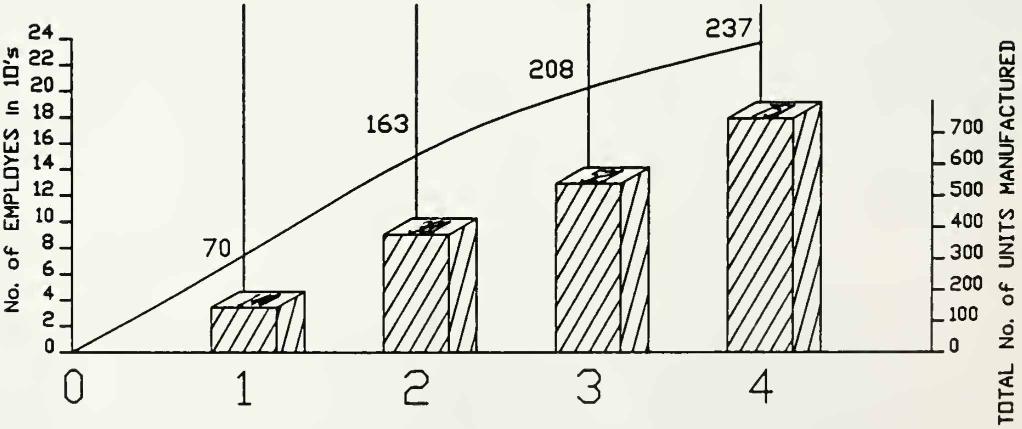


FIGURE 5-2

The base-line, 3,000 horsepower engine model can be re-rated or reconfigured to produce an engine family rated from 1,500 to 15,000 horsepower. This serves a major market in locomotive, marine, stationary and mobile power generation, industrial vehicles, and co-generation applications.

A major goal of end users in these applications is the reduction of fuel costs as well as over-all costs. Railroads are currently spending about three-fourths of their operating budgets on fuel. If converted from diesel to mine-mouth coal, locomotive operating costs would be halved. Even greater savings are possible to the user who is producing a fuel, such as coal mines, wood products plants, municipalities, farmers, etc.

Total cost must also include purchase price of the engine/system and cost of installation as well as operating costs. Competitive engines consist of large diesels and small and medium sized steam and gas turbines. These can be purchased for about 95 to 300 dollars per horsepower. The Unitary Steam Engine can be produced for about 65 dollars per horsepower leaving room for a good profit margin when sold at a competitive price. However, sufficient savings generated by use of a cheaper fuel can offset a greater installation cost. As an example, mine-mouth coal at $14 per ton can be compared to #2 fuel oil at $0.65 per gallon. If a 3,000 horsepower, 35% thermally efficient engine is operated at 50% availability, it will consume $431,039 in fuel oil versus $62,732 in coal. This represents a savings in fuel costs of $368,307. Such a savings in fuel pays for the cost of installing the Engine and begins to create a return on investment within the first year of operation, even if the engine were sold for as much as $120 per horsepower. Obviously, these fuel savings do not apply to engines which cannot burn solid fuel. A fairly large market share is envisioned as being vulnerable to penetration by the Unitary Steam Engine because of its great fuel tolerance.

The projected economic impact on the State of Montana for the year 2000 is summarized in Table 5-1. This table shows the number of jobs, total payrolls, sales, and taxes expected to be created five years after the start of manufacture of the Unitary Steam Engine. The table shows the impact in terms of closely related spin-off businesses as well as the direct impact of

TABLE 5-1

PROJECTED ECONOMIC IMPACT IN TWELVE YEARS/AFTER FIVE YEARS' MANUFACTURE

U.S. ENGINE	EMPLOYEES	ANNUAL PAYROLL (Millions)	ANNUAL SALES (Millions)	PERSONAL INCOME TAXES (Millions)	CORPORATE TAXES (Millions)
- Engine Factory	400	$ 8.0	$108.16	$ .400	$ 1.5
- Locomotive Installations (at 10 to 15% of combined locomotive replacement/ locomotive re-engine market)	225	4.5	41.0	.225	.5
- Gen-Sets	70	1.5	17.0	.075	.175
- Engine Rebuilding	100	2.0	20.9	.100	.275
	(795)	(16.0)	(187.06)	(.800)	(2.450)
COZBY ENTERPRISES					
- Co-Generation Application & Engineering Services	15	.500	2.5	.025	.025
- Service Training	30	.900	5.0	.045	.050
- Printing/Publications	15	.350	4.0	.0175	.050
	(60)	(1.75)	(11.5)	(.0875)	(.125)
OTHERS					
- Foundry (additional)	75	1.5	5.0	.075	.050
- Home Heating	50	1.0	9.0	.050	.090
	(125)	(2.5)	(14.0)	(.125)	(.140)
TOTALS	980	$20.25	$212.56	$1.0125	$2.715

manufacture. Spin-off businesses include expansion related to Engine repairs, installation, or other service related requirements.

At this point, a major expansion will be necessary in order to capture a larger share of the market niche originally targeted and attack a larger market within an expanded product line. In order to do this, an investment of approximately $500 million will be required. This degree of investment will create conditions favorable to allow the long range forecasts that follow.

Projecting 25 years after the original start of manufacture to about the year 2013, the market should achieve a relatively stable, steady demand of about 7,000 units per year. With this factor as a basis, other related businesses are computed as to their economic impact on the State. It is important to note that the great majority of end-users are out-of-state customers, and therefore, the dollars generated as sales are seen to be increasing the total wealth of the State. Also the total economic impact of the figures presented, particularly annual payrolls, must be multiplied by the effect of increased business and development of other community support services. This effect has been stated to be 3 to 7 times the amount of newly established business payrolls.

The long range projected economic impact on the State is shown in Table 5-2, where jobs, payrolls, sales, and taxes for the year 2013 are estimated based on the foregoing assumption.

TABLE 5-2

LONG RANGE PROJECTED ECONOMIC IMPACT: 2013, A 25-YEAR FORECAST

U.S. ENGINE	EMPLOYEES	ANNUAL PAYROLL (Millions)	ANNUAL SALES (Millions)	PERSONAL INCOME TAXES (Millions)	CORPORATE TAXES (Millions)
- Engine Factory(ies)	5,050	$126.25	$1,925.0	$ 6.3125	$20.0
- Locomotive Installations	2,250	56.25	512.5	2.8125	5.0
- Gen-Sets	1,000	26.8	303.6	1.34	3.0
- Co-Gen Installations	40	1.0	20.0	.05	.2
- Engine Rebuilding	1,000	25.0	260.0	1.25	3.0
- Parts & Service	1,010	31.6	575.0	1.6	5.0
	(10,350)	(266.9)	(3,596.1)	(13.365)	(36.2)
COZBY ENTERPRISES					
- Engineering & Special Services	75	3.25	16.0	.17	.2
- Training Services	150	5.6	50.0	.3	.3
- Publications	150	4.375	50.0	.24	.6
	(375)	(13.225)	(116.0)	(.71)	(1.1)
OTHERS					
- Foundry/Materials Suppliers	1,050	26.25	224.0	1.3	3.0
- Transportation	325	8.125	63.0	.4	1.0
- Home Heating	125	3.5	25.0	.2	.25
	(1,500)	(13.875)	(312.0)	(1.9)	(4.25)
TOTALS	12,225	$318.0	$4,024.1	$15.975	$41.55

6.0 GRANT ADMINISTRATION

This section of the report includes an evaluation of the project in terms of time and money. Section 6.1 compares time scheduled to time expended and Section 6.2 presents the accounting figures relevant to completion of each milestone.

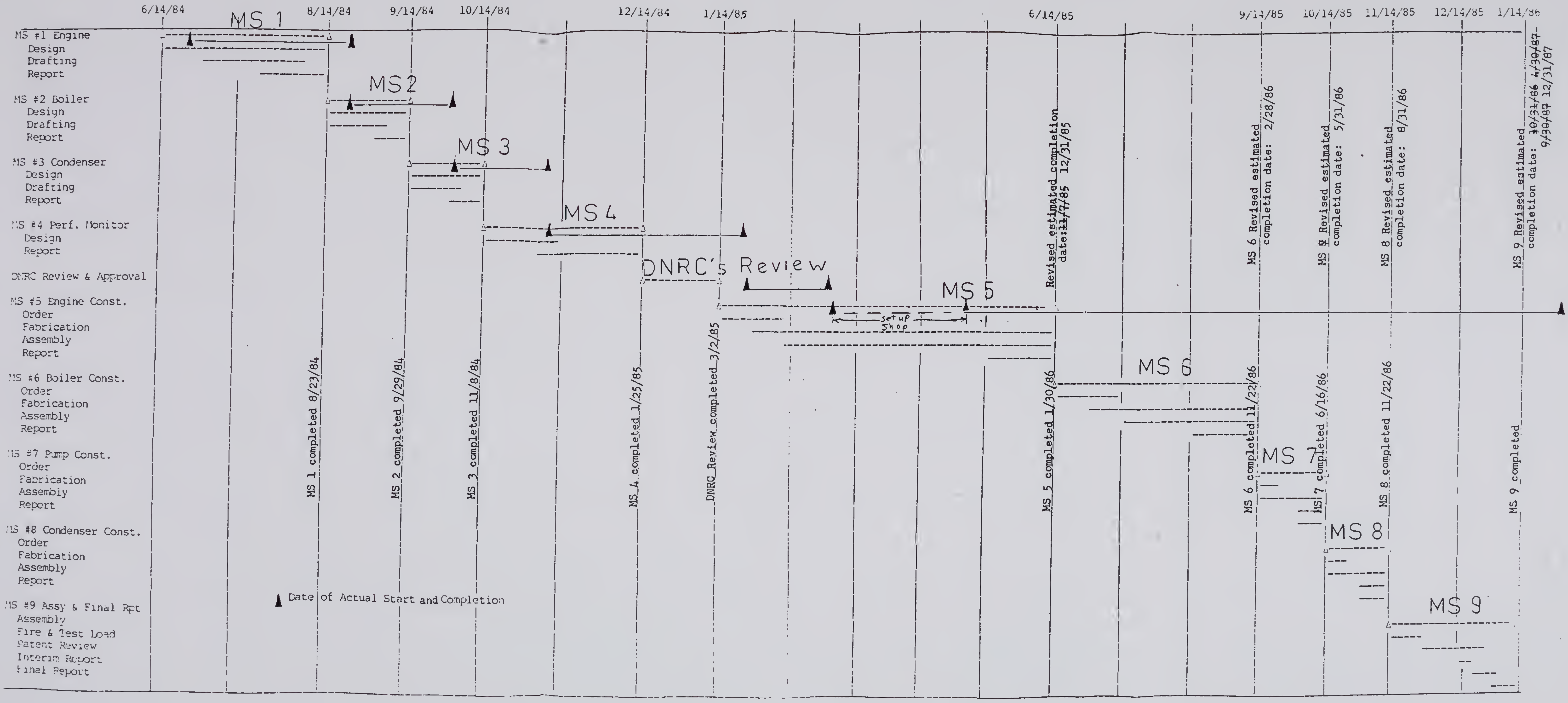
6.1 SCHEDULE

Contract No. RAE-84-1046 was signed June 14, 1984. Initial design work commenced June 25, 1984. The interim period was used in project mobilization which included securing and organizing office space in Butte, working on obtaining a line of credit to finance the project, finalizing subcontracted consultant services, and organizing staff responsibilities.

A project schedule was developed to chart the milestone dates for successful project completion (see the following milestone schedule). As work progressed, revisions to the projected timetable were noted on the schedule. The actual start and completion dates are entered to track progress.

A contributing factor to project delays was the unfortunate automobile accident that the project director was involved in on July 14, 1984. In order to meet the requirements of the contract, staff duties were shifted and additional contributed time was used to complete the project.

The amount of time required to set up the fabrication shop was not budgeted in the schedule and was greater than anticipated. Delays in delivery of machinery and tools, repair of tools, and fabrication of special tooling caused further setbacks. Some time was required to correct errors in the Astralloy crankcase plates, which were delivered with holes in the wrong places. The machinable ceramic did not work as readily or as rapidly as advertised, and consequently considerable extra time was spent working on the ceramic parts. (In manufacture, the parts which are specified as being ceramic will be made of fired ceramic and will not present the problems presented by the machinable ceramic.) Due to the intricacy and sheer number of parts, the amount of time necessary for machining was greater than had been scheduled. Other



Milestone Schedule

contributing factors to the overall project delays and descrepancies are discussed in Section 2.4.

6.2 BUDGET

Total funding allocated to Milestone 1 was $23,345. Actual expenses and costs are detailed in Section 6.2.1.

Total funding allocated to Milestone 2 was $12,540. Actual expenses are detailed in Section 6.2.2

Total funding allocated to Milestone 3 was $11,140. Actual expenses are detailed in Section 6.2.3.

Total funding allocated to Milestone 4 was $19,210. Actual expenses are detailed in Section 6.2.4

Total funding allocated to Milestone 5 was $111,560. Actual expenses are detailed in Section 6.2.5.

Total funding allocated to Milestone 6 was $34,600. Actual expenses are detailed in Section 6.2.6.

Total funding allocated to Milestone 7 was $16,045. Actual Expenses are detailed in Section 6.2.7.

Total funding allocated to Milestone 8 was $15,410. Actual expenses are detailed in Section 6.2.8.

Total funding allocated to Milestone 9 was $20,650. Actual expenses are detailed in Section 6.2.9.

Following each detailed milestone financial report is a cumulative report tracking progress to project completion. The total DNRC funding allocated to this project was $264,500.

6.2.1 Milestone 1 Financial Report

June 14 - August 23, 1984

Salaries & Wages*	$ 8,338.62
Contracted Services (Multitech)	12,600.00
Communications	64.71
Travel	37.94
Rent & Utilities	607.50
Supplies & Materials	581.07
Miscellaneous & Indirect	1,551.00
TOTAL, MILESTONE 1	$ 23,780.84

*Total Milestone 1 Hours	816
Charged to DNRC	725.1
Balance (contributed by Cozby Enterprises)	90.9

Note: During this Milestone, 856.75 hours were logged, but 40.75 hours were spent on Milestone 4 work and will be charged to that Report.

6.2.2 Milestone 2 Financial Report

August 23 - September 29, 1984

Salaries & Wages*	$ 4,173.88
Contracted Services (Multitech)	7,200.00
Communications	118.81
Travel	0.00
Rent & Utilities	337.50
Supplies & Materials	71.47
Miscellaneous & Indirect	616.93
TOTAL, MILESTONE 2	$ 12,518.59

*Total Milestone 2 Hours	400.75
Charged to DNRC	363
Balance (contributed)	37.75

6.2.2.1 Milestone 2 Cumulative Report

June 14 - September 29, 1984

Salaries & Wages*	$ 12,512.50
Contracted Services (Multitech)	19,800.00
Communications	183.52
Travel	37.94
Rent & Utilities	945.00
Supplies & Materials	652.54
Miscellaneous & Indirect	2,167.93
TOTAL EXPENDITURES, MILESTONES 1 & 2	$ 36,299.43

*Total Hours	1,216.75
Charged to DNRC	1,088.1
Balance (Contributed)	128.65

Note: During Milestone 1, 40.75 hours were spent on Milestone 4 work and are not included in the above summary of hours.

6.2.3 Milestone 3 Financial Report

October 1 - November 8, 1984

Salaries & Wages*	$ 4,123.53
Contracted Services (Multitech)	5,500.00
Communications	163.38
Travel	35.00
Rent & Utilities	360.00
Supplies & Materials	163.93
Miscellaneous & Indirect	497.03
TOTAL, MILESTONE 3	$ 23,780.84

*Total Milestone 3 Hours	427.25
Charged to DNRC	358.6
Balance (contributed)	68.65

6.2.3.1 Milestone 3 Cumulative Report

June 14 - November 8, 1984

Salaries & Wages*	$ 16,636.03
Contracted Services (Multitech)	25,300.00
Communications	346.90
Travel	72.94
Rent & Utilities	1,305.00
Supplies & Materials	813.47
Miscellaneous & Indirect	2,664.96
TOTAL EXPENDITURES, MILESTONES 1 - 3	$ 47,139.30

*Total Hours	1,644
Charged to DNRC	1,446.7
Balance (contributed)	197.3

Note: During Milestone 1, 40.75 hours were spent on Milestone 4 work and are not included in the above summary of hours.

6.2.4 Milestone 4 Financial Report

November 9, 1984 - January 25, 1985

Salaries & Wages*	$ 9,175.97
Contracted Services (Multitech)	8,734.13
Communications	194.80
Travel	41.44
Rent & Utilities	675.00
Supplies & Materials	84.34
Miscellaneous & Indirect	735.29
TOTAL, MILESTONE 4	$ 19,643.91

*Total Milestone 4 Hours	798	(includes 40.75 hours from Milestone 1 timeframe)
Charged to DNRC	798	
Balance (contributed)	-0-	

Explanatory Notes:

This Report reflects some corrections in charges from previous Milestone Reports. ie: errors in charging hours; charges placed in incorrect categories.

These charges do not reflect all expenditures by Cozby Enterprises during this time period, only that amount that comes up to the cumulative amount allowable .

6.2.4.1 Milestone 4 Cumulative Report

June 14, 1984 - January 25, 1985

Salaries & Wages*		$ 25,812.00
Contracted Services (Multitech):		
Current Charges	$ 34,034.13	
⁑'Cost of Report' from Miscellaneous & Indirect	924.50	
		34,958.63
Communications		541.70
Travel		114.38
Rent & Utilities		1,980.00
Supplies & Materials		897.81
Miscellaneous & Indirect:		
Current Charges	3,400.25	
⁑'Cost of Report' to Contracted Services	(924.50)	
		2,475.75
TOTAL EXPENDITURES, MILESTONES 1 - 4		$ 66,780.27

*Total Hours	2,442
Charged to DNRC	2,244.7
Balance (contributed)	197.3

⁑Since the Cost of Report is an item paid directly to Multitech, it properly belongs in the Contracted Services account rather than in Miscellaneous & Indirect. By transferring that item, this Cumulative Report more properly reflects the amounts that were expended for each line item.

6.2.5 Milestone 5 Financial Report

March 1, 1985 - January 30, 1986

Salaries & Wages*		$ 42,600.00
Contracted Services:		
Multitech	$ 8,030.00	
Other Machining	9,170.00	17,200.00
Communications		925.00
Travel		85.00
Rent & Utilities		4,100.00
Equipment & Materials		44,988.31
Miscellaneous & Indirect		1,661.69
TOTAL, MILESTONE 5		$111,560.00

*Total Milestone 5 Hours	5,075.25
Charged to DNRC	3,704.4
Balance (contributed)	1,370.85

Note: During this Milestone, 5,165.25 hours were logged, but 90 hours were spent on Milestone 8 work and will be charged to that Report.

6.2.5.1 Milestone 5 Cumulative Financial Report

June 14, 1984 - January 30, 1986

Salaries & Wages*		$ 68,412.00
Contracted Services:		
Multitech	$ 42,988.63	
Other	9,170.00	52,158.63
Communications		1,466.70
Travel		199.38
Rent & Utilities		6,080.00
Equipment, Supplies, & Materials		45,886.12
Miscellaneous & Indirect		4,137.44
TOTAL EXPENDITURES, MILESTONES 1 - 5		$178,340.27

*Total Hours	7,517.25
Charged to DNRC	5,949.1
Balance (contributed)	1,568.15

Note: During Milestone 5, 90 hours were spent on Milestone 8 work and are not included in the above summary of hours.

6.2.6 Milestone 6 & 8 (Combined) Financial Report

January 31,1986 - November 22, 1986

Salaries and Wages*		$ 24,328.75
Contracted Services:		
Multitech	$ 695.00	
Other Machining	11,198.50	
		11,893.50
Communications		785.22
Travel		0.00
Rent & Utilities		2,160.00
Equipment & Materials		19,559.86
Miscellaneous & Indirect		635.99
TOTAL, MILESTONES 6 & 8		$ 59,363.32

NOTE: Milestone 6 is combined with Milestone 8 because both were completed and billed to the State at the same time.

*Total Milestone 6 & 8 Hours	2,117	(includes 90 hours from Milestone 5 timeframe)
Charged to DNRC	2,115.6	
Balance (contributed)	1.4	

6.2.6.1 Milestone 6 Cumulative Report (Including MS 8)

June 14, 1984 - November 22, 1986

Salaries & Wages*		$ 92,740.75
Contracted Services		
Multitech	$ 43,683.63	
Other Machining	20,368.50	
		64,052.13
Communications		2,251.92
Travel		199.38
Rent & Utilities		8,240.00
Equipment, Supplies, & Materials		65,445.98
Miscellaneous & Indirect		4,773.43
TOTAL EXPENDITURES, MILESTONES 1 - 6		$237,703.59

*Total Hours	9,634.25
Charged to DNRC	8,064.7
Balance (contributed)	1,569.55

6.2.7 Milestone 7 Financial Report

January 31 - June 16, 1986

Salaries & Wages*		$ 10,999.40
Contracted Services:		
Multitech	$ 1,501.00	
Other Machining	18.00	
		1,519.00
Communications		408.18
Travel		0.00
Rent & Utilities		1,800.00
Equipment & Materials		3,817.81
Miscellaneous & Indirect		1,190.46
TOTAL, MILESTONE 7		$ 19,734.85

*Total Milestone 7 Hours	2,449.75
Charged to DNRC	956.5
Balance (contributed)	1,493.25

6.2.7.1 Milestone 7 Cumulative Financial Report

June 14, 1984 - June 16, 1986

Salaries & Wages*		$103,740.15
Contracted Services:		
Multitech	$ 45,184.63	
Other Machining	20,386.50	65,571.13
Communications		2,660.10
Travel		199.38
Rent & Utilities		10,040.00
Equipment, Supplies, & Materials		69,263.79
Miscellaneous & Indirect		5,963.89
TOTAL EXPENDITURES, MILESTONES 1 - 7 (8)		$257,438.44

*Total Hours	12,084
Charged to DNRC	9,021.2
Balance (contributed)	3,062.8

6.2.8 Milestone 8 Financial Report

March 14 - November 22, 1986

The Milestone 8 work was done concurrently with the Milestone 6 work, and both Milestones were submitted to the State at the same time. For accounting purposes, the two Milestones were submitted jointly. Therefore, no separate Milestone 8 report has been prepared since the separate accountability lines were not allocated so as to differentiate between the two milestones. Please refer to the Milestone 6 Financial Report for accounting figures.

6.2.8.1 Milestone 8 Cumulative Financial Report

June 14, 1984 - November 22, 1986

Since the work for Milestone 8 was charged off along with Milestone 6, the accumulated expenses have already been reported.

6.2.9 Milestone 9 Financial Report

November 23, 1986 - December 31, 1987

Salaries & Wages*	$ 21,500.00
Contracted Services	593.00
Communications	364.59
Travel	35.00
Rent & Utilities	2,520.00
Equipment & Materials	364.28
Miscellaneous & Indirect	0.00
TOTAL, MILESTONE 9	25,376.87

*Total Milestone 9 Hours	4,350.5
Charged to DNRC	1,869.6
Balance (contributed)	2,480.9

6.2.9.1 Milestone 9 Cumulative Financial Report

June 14, 1984 - December 31, 1987

Salaries & Wages*		$125,240.15
Contracted Services:		
Multitech	$ 45,184.63	
Other	20,979.50	66,164.13
Communications		3,024.69
Travel		234.38
Rent & Utilities		12,560.00
Equipment, Supplies, & Materials		69,628.07
Miscellaneous & Indirect		5,963.89
TOTAL EXPENDITURES, MILESTONES 1 - 9		$282,815.31

*Total Hours	16,434.5
Charged to DNRC	10,890.8
Balance (contributed)	5,543.7

Note: At $11.50 an hour, the contributed portion of the Project attains a value of $63,752.55. This contributed value plus additional contributed funds **not** accrued in the accounting could be added to the total expenditures of $282,815.31 for a total project cost.

6.3 SUBCONTRACTED SERVICES

A subcontract was negotiated with MultiTech Services Division of MSE Inc. of Butte, Montana to provide technical services as required to support Cozby Enterprises, Inc. in the completion of DNRC Contract No. RAE-84-1046.

MultiTech provided engineering services in the analysis of various structural components, thermodynamic cycles, cam design, pump hydraulic characterization and individual component requirements as included in Appendix E.

Concurrent with the progress of the project, MultiTech provided project management and administrative services to ensure that the project was proceeding in a manner to support the contractual obligation of Cozby Enterprises, Inc. The project milestone schedules as well as drawings on the project were developed by MultiTech. Design consultation, evaluation, and review were provided to support the design packages required for the fabrication of the Unitary Steam Engine. MultiTech also participated in the documentation and preparation of the project reports.

7.0 SLIDE SHOW

This section of the report presents a tabulation of the photographic slides which show various aspects of construction and assembly of the Engine. These slides may be supplemented by pictures taken by DNRC. The slides can be used to show the work accomplished during this project. Additionally, DNRC is in possession of a video-tape record showing some testing and evaluation work. The slides are briefly described in the following table:

001,002,003: Indicate the work accomplished during milestones 1-4 during the engineering recheck phase.

001: Shows John Cozby detailing specific dimensions.

002: Review of engineering data by Multitech, Rich Fullmer preparing the Energy Balance worksheets.

003: Drafting services by MultiTech - Martin Moe drawing.

004: Support frame.

005-009: Components in the making.

005: Lp cylinder being welded by Frank Johns, Cozby Enterprises machinist.

006: Lp cylinder under visual inspection by Frank Johns.

007: Lp cylinder mounted on mill.

008: Ip cylinder mounted on mill.

009: Cylinder head mounted on mill.

010: On-site inspection by DNRC's Howard Haines; John Cozby, Frank Johns.

011: Lp cylinders flanking Hp/water injector cylinders, sitting on cylinder head. Note assembly shaft mounted in valve operator case in background. Note: this slide needs very dark room and bright projector to be seen.

012: Crankshaft; valve operator case with assembly shaft mounted; Lp-Ip-Lp cylinders assembly; crankcase furnace plate/seal housing; Ip, Hp, Lp cylinders on cylinder head.

013: Valve operator case mid-plate view.

014: Side view of valve operator case with crankshaft installed and flywheel/flywheel pulleys.

015: Cylinder skeleton assembly, front view; shows: two Lp exhaust headers; heads; Lp, Ip, Hp, water injector cylinders; crankcase walls; cross-arm assemblies; Hp pistons; water injector plungers; Ip stage valve cases.

016: Cylinder skeleton assembly, rear perspective view; shows same as 015 and also two Lp injection headers.

017: Cylinder skeleton assembly, rear view; note Ip stage valve operator arms.

018: Cylinder skeleton assembly mounted to valve operator case, front view. Pistons and crossarm assemblies removed.

019: Cylinder skeleton assembly mounted to valve operator case, front perspective view. Pistons and crossarm assemblies removed.

020: Crankshaft mounted in valve operator case, showing the throws.

021: Crankshaft mounted in valve operator case, perspective.

022: Expander basic assembly, laid horizontal, crankcase furnace plate removed.

023: Expander basic assembly, laid horizontal, crankcase furnace plate aligned for installation.

024 - 027: Expander basic assembly, crankcase furnace plate removed to show crankshaft - pistons interaction.

024: Showing TDC position for Hp and Lp stages/BDC for Ip stage.

025: Showing rotation to indicate injection for Hp and Lp stages/exhaust for Ip stage.

026: Showing BDC for Hp and Lp stages/TDC for Ip stage.

027: Showing rotation to indicate exhaust for Hp and Lp stages/ injection for Ip stage.

028: Valve operator case, and view with crankcase flywheel plate removed; Ip assemblies visible.

029: Valve operator case, end perspective view, valve rockers and rocker support plates visible.

030: Valve operator case, end view, showing cam follower plate assembly.

031: Valve operator case, end perspective, showing cam follower plate assembly.

032: Top view of top Ip cylinder and cam plate assembly.

033: End view, valve operator section; engine brake : bearing, bearing housing, arms, shaft.

034: End perspective view, valve operator section; engine brake.

035: Top view of top Ip cylinder and cam plate holder with engine brake installed.

036: Engine brake lever installed on valve operator case.

037: Cam sleeve components: Ip/Lp advance mechanism, Ip/Lp cam sleeve, brake bearing/bearing housing, Hp cam sleeve, Hp advance mechanism rings.

038: Cam sleeve assembly; mounted in lathe for operational testing of centrifugal advance mechanisms.

039: Oil pump assembly

040: End perspective view, valve operator section with oiling system installed.

041: Elevated perspective end view of valve operator section.

042: Flywheel plate in place, flywheel installed.

043: Showing set up to drive the mechanics with an electric motor to test rotational/reciprocating operation.

044: Steam generator components: furnace wall, outer shell pieces, tubing-coils and straight pieces, furnace burner plate.

045: Steam generator components: coils of tubing, transition piece, controller column, superheater coils, lengths of straight tubing.

046: Recuperator tubes and fuel preheat tubes installed on inner wall of recuperator, ready to be enclosed.

047: Initial design burner assembly in test stand ready for initial test firing.

048: Steam generator front plate assembly on mill, with burners located, for cutting air, gas, steam ports.

049: Steam generator front plate assembly.

050: End view, steam generator front plate assembly installed on steam generator support; air, gas, steam ports, ignitor wires visible.

051: End view, air, gas, steam cover plate installed on steam generator front plate; furnace access covers installed on furnace front plate.

052: View from inside steam generator support shell; showing burners with ignitor system protection manifold installed.

053: View from inside steam generator support shell showing burners with ignitor system protection manifold installed; one burner undergoing ignition testing.

054: Steam generator rear perspective. Note: the internal cross braces shown were later removed.

055: Steam generator rear perspective. The internal cross braces have been removed. The deflector shield shown was also later deleted from the design.

056: Controller column located beside steam generator. End view through steam generator shell showing expander.

057: Controller column, perspective view, mounted on Engine.

058: Controller column, showing insulation wrap.

059: End view, #1 reheaters installed on expander; transition piece fitted to expander.

060: Side view, #1 reheaters installed, #2 reheaters in process of being installed, transition piece removed.

061: Perspective view, #1 reheaters installed, #2 reheaters in process of being installed.

062: Perspective view, #1 reheaters installed, #2 reheaters in process of being installed.

063: End perspective, #2 reheaters completed and installed.

064: Reheaters installed, transition piece refitted, initial design throttle installed.

065: Perspective view, superheater fitted inside reheaters.

066: Steam generator ready to be assembled to the expander/reheater assembly.

067: Steam generator being brought up to the expander/reheater assembly.

068: Steam generator drawn up into place against the expander.

069: Steam generator/expander assembly.

070: Parts of the vacuum pump laid out on the hotwell (water reservoir)

071: Vacuum pump assembled and installed on hotwell; hotwell installed on frame; steam generator not shown.

072: Vacuum pump; condenser being fitted.

073: Tubes for expansion chamber-to-condenser connections.

074: Condenser assembly: condenser, fan, hydraulic motor drive, hot well.

075: Elevated perspective showing condenser, one exhaust stack, blower, blower motor, hydraulic reservoir.

076: Hydraulic reservoir with hydraulic pump installed; located for installation on the expander.

077: Hydraulic reservoir installed and connected for drive to the driveshaft pulleys; initial fuel system installed.

078: Initial design throttle; hydraulic reservoir.

079: Major components of the Engine assembled, transition piece partly disassembled.

080: Major Engine components assembled.

081: Water system solenoid valves and associated piping. Note also control panel, initial design 12v starter motor system.

082: Control panel, initial design starter motor system. Engine assembly progressing.

083: Engine assembly progressing, rear perspective.

084: Engine assembly progressing, front perspective.

085: Controller relays being wired in.

086: Engine assembly progressing, back side view.

087: Engine assembly progressing, rear perspective view, outer shell insulation being installed.

088: Engine assembly progressing, side view.

089: Engine assembly progressing, front view.

090: John Cozby with Engine near completion.

091: Final connections being attached.

092: Engine being connected for test firing on propane.

Note: Slides showing final modifications, reassembly, and testing were lost.

8.0 PATENT SUMMARY

During the course of the project some items were found that might require patent protection investigation. For instance, the vacuum pump modifications and revisions may be sufficiently different to be a patentable innovation although the basic design is already covered by the existing patent. A great deal of time and money would be required for the developmental work to pursue the appropriateness of additional patent applications. There is no provision for funding in this project for that work.

The Unitary Steam Engine Patent No. 4,395,885 is still valid and should cover the concepts of the Engine as developed to date.

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APPENDIX A

UNITED STATES PATENT 4,395,885 ABSTRACT

United States Patent [19]

Cozby

[11] **4,395,885**

[45] **Aug. 2, 1983**

[54] UNITARY STEAM ENGINE

[75] Inventor: John A. Cozby, Anaconda, Mont.

[73] Assignee: Cozby Enterprises, Inc., Anaconda, Mont.

[21] Appl. No.: **309,707**

[22] Filed: **Oct. 8, 1981**

[51] Int. Cl.^{3} **F01K 11/00**

[52] U.S. Cl. **60/669**; 60/660; 60/667; 60/670

[58] Field of Search 60/643, 645, 660, 667, 60/669, 670, 716, 720

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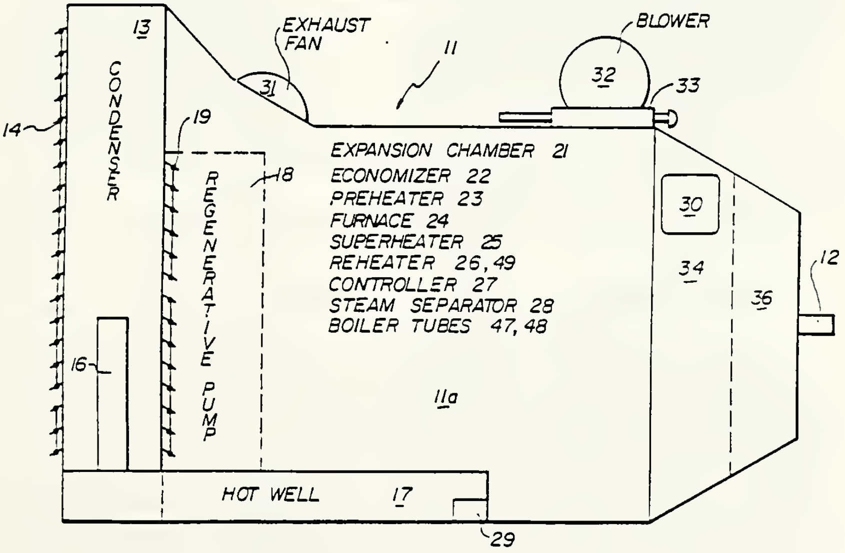
Primary Examiner—Allen M. Ostrager
Assistant Examiner—Stephen F. Husar
Attorney, Agent, or Firm—Blair, Brown & Kreten

[57] **ABSTRACT**

Disclosed herein is a steam engine suitably constructed to serve as a prime mover. The device includes a furnace in which a liquid can be heated so as to change its phase, the thus formed gas directed to an engine whereupon its expansion within piston/cylinder arrangements provides useful work. The exhausted steam, still endowed with extractable energy, is passed through various regenerative pump mechanisms and the like for very efficient utilization of much of the inherent energy.

42 Claims, 47 Drawing Figures



UNITARY STEAM ENGINE

BACKGROUND OF THE INVENTION

One of the earliest types of engines for performing work such as driving a load is the steam engine and at one time virtually all such engines were steam driven. While such steam engines performed satisfactorily in spite of their relatively low efficiency, subsequent developments in engine design produced engines of greater efficiency and higher horsepower to weight ratios such as the internal combustion engine, the steam turbine and the like. As a result, the use of steam engines became more and more rare so that today one seldom sees steam engines of these earlier types.

With the development of the motor vehicle, efforts were made to incorporate such a steam engine as the power unit for the vehicle but such efforts were short lived due to a number of difficulties and thus the internal combustion engine rapidly became the accepted power unit for the motor vehicle. As a result of such widespread acceptance for the internal combustion engine or gas turbine engine the steam engine as a power unit has been virtually eliminated from industrial and transportation use. Accompanying such lack of interest in the steam engine was the bringing of research and development of steam engines to a virtual stand still. However, there has been a renewed interest in steam engines as a result primarily of environmental and pollution considerations and from the continuing rise in the price of fossil fuels such as oil.

The following patents are representative of the prior art to which the subject invention pertains all of which are clearly distinguishable both structurally and functionally from applicant's steam engine:

1,160,445 Patitz, 2,295,962 Mueller, 1,440,623 Parente, 2,730,996 Doble, 1,690,129 Nielebock, 3,995,531 Zibrun, 1,962,986 Dole.

The steam engines described in the prior art patents listed above incorporate some elements which are similar in construction to some of the elements of the subject invention. However, none of these prior art engines disclose the specific new and novel combination of elements by means of which the new and unexpected results are obtained in accordance with applicant's invention.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, a primary object of this invention is to provide a new and novel steam engine of the condensing type which is ideally suited as a power unit for a motor vehicle prime mover or the like. The term steam is used in reference to vapor characteristics, other liquids which produce usable vapor pressure are also contemplated.

Another object of this invention is to provide a new and novel unitary steam engine which may be operated at a high level of efficiency and which utilizes steam to high expansion with low thermal loss.

A further object of this invention is to provide a new and novel unitary steam engine which is of extremely compact construction, provides a highly favorable power to weight ratio and which is extremely quiet in operation.

Still another object of this invention is to provide a new and novel unitary steam engine which is substantially nonpolluting, which requires a minimum of maintenance, which may be produced at low cost and a high rate of production, and is easy to service.

A still further object of this invention is to provide a new and novel unitary steam engine which may be adapted for use with a variety of fuels and/or heat sources and which provides for engine braking power and utilizes the principle of direct conversion of heat energy to motive power.

A further object of this invention is to provide an engine which effectively separates steam and lubricant, keeping the steam pure and dry while at the same time providing adequate lubrication where needed.

Still another object of this invention is to provide very little valve clearance space in order to reduce dead waste space and to be able to better utilize high ratios of expansion.

Also, an object of this invention is to provide high flow rates for steam in order to facilitate high piston speeds and high rotative speeds.

Another object of this invention is to keep compression to a minimum by incorporating a novel means of valve movements, allowing almost total exhaust during exhaust stroke.

A still further object of this invention is to divide piston loads to achieve the best over all advantage.

Another object of this invention is to provide an engine with excellent balance of reciprocating elements and balance of forces applied to the crank shaft.

Another object of this invention is to produce a unit which possesses great intrinsic strength and rigidity.

Yet another object of this invention is to provide a system in which the caloric content of the fuel is used to a high extent with little loss.

Another object of this invention is to utilize exhaust steam heat which is normally discarded to improve the steam cycle efficiency and furnace efficiency.

Another object of this invention is to incorporate within the structure a regenerative feed water heat pump to aid in improving the steam cycle.

Another object of this invention is to provide for a simple automatic control for the functions of the furnace and boiler.

Another object of this invention is to provide means of giving the engine high overload capacities both automatically and manually.

Another object of the invention is to incorporate a means to produce distilled make-up feed water.

Another object of this invention is to provide means for additional deaerating of the system.

The objects stated above and other related objects are accomplished by providing a casing having a source of fuel therein together with an enclosure including a furnace for burning the fuel to create hot combustion gases with a plurality of coaxially arranged tubular partitions of circular cross-sectional shape surrounding the furnace. The tubular partitions define a plurality of radially spaced annular chambers, and an axially extending drive shaft is rotatably mounted within a central passage provided within the enclosure, the drive shaft having an end portion extending outwardly from the casing for driving connection to an associated unit to be driven. A plurality of annularly arranged boiler tubes are provided in a first one of the annular chambers over which hot combustion gases from the furnace flow and means are provided for circulating from a source of water in the casing through the boiler tubes for generating steam. A plurality of cylinder/piston assemblies are mounted in the casing, the pistons of which are drivably connected to the drive shaft and means are provided including a throttle and a plurality of slide valves each operatively associated with one of the cylinder/piston assemblies to conduct the generated steam to the cylinder/piston assemblies for reciprocating said piston to rotate the drive shaft. Cam means are provided on the drive shaft for actuating the slide valves in a timed relationship and means including a condenser are provided for converting the steam exhausted from the cylinder/piston assemblies into condensate and means are provided for returning the condensate to the boiler tubes in a closed system.

Other objects and advantages will become apparent in the following specification when considered in light of the attached drawings.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a flow chart illustrating the interconnection of the various components of the invention so as to reflect their sequential operation;

FIG. 2 is a side elevation view of the steam engine of the invention with the disposition of the parts identified therein;

FIG. 3 is an enlarged longitudinal section view of a portion of the steam engine of FIG. 10;

FIG. 4 is an end view of a portion of the engine of FIG. 2 illustrating the disposition of the cylinder/piston assemblies incorporated therein;

FIG. 5 is a schematic showing of a modification of the driving arrangement of FIG. 4;

FIG. 6 is a schematic showing of another modification of the driving arrangement of FIG. 4;

FIG. 7 is a schematic showing of a further modification of the driving arrangement of FIG. 4;

FIG. 8 is a schematic showing of a modification of the pressure stages of the invention and admitting of additional crank pin positions, as at 90°;

FIG. 9 is a view similar to FIG. 8 showing schematically another modification of the pressure stages of the invention and admitting of additional crank pin positions, as at 90°;

FIG. 10 is a view similar to FIG. 4 showing a modified arrangement for the cylinder/piston assemblies of the invention;

FIG. 11 is an end view illustrating a cam actuating mechanism for a slide valve incorporated in the invention;

FIG. 12 is an end view illustrating a cam actuating arrangement for the slide valves incorporated in the invention;

FIG. 13 is a view similar to FIG. 12 showing another cam actuator;

FIG. 14 is a view similar to FIG. 13 showing another cam actuator;

FIG. 15 is an end view illustrating a portion of the high pressure valve cam advance utilized in a valve cam mechanism assembly incorporated in the invention;

FIG. 16 is a view similar to FIG. 15 illustrating another portion of the high pressure valve cam of FIG. 15;

FIG. 17 is a view similar to FIG. 15 showing still another portion of the cam of FIG. 15;

FIG. 18 is a side view of the valve cam mechanism assembly and injection cam advance incorporated in the engine of the invention;

FIG. 19 is a side view of the low pressure slide valve head assembly incorporated in the invention;

FIG. 20 is a sectional plan view of FIG. 19 taken substantially along lines 20—20 in the direction of the arrows;

FIG. 21 is a side view of the high pressure slide valve head assembly incorporated in the invention;

FIG. 22 is a sectional plan view taken substantially along lines 22—22 of FIG. 21 in the direction of the arrows;

FIG. 23 is a sectional plan view of another slide valve assembly incorporated in the steam engine of the invention;

FIG. 24 is a sectional view taken substantially along lines 24—24 of FIG. 23 in the direction of the arrows;

FIG. 25 is an end view of the regenerative pump incorporated in the the steam engine of the invention;

FIG. 26 is a sectional view of the receiver pressure regulator incorporated in the steam engine of the invention;

FIG. 27 is a plan view of the throttle valve incorporated in the steam engine of the invention;

FIG. 28 is a sectional side view taken substantially along lines 28—28 of FIG. 27 in the direction of the arrows;

FIG. 29 is a sectional end view of the furnace and surrounding parts incorporated in the steam engine of the invention;

FIG. 30 is a side elevation view partially in section of the controller incorporated in the invention;

FIG. 31 is a perspective view of the steam separator incorporated in the invention;

FIG. 32 is a longitudinal sectional view taken substantially along lines 32—32 of FIG. 29 in the direction of the arrows showing one of four furnace areas;

FIG. 33 is an end view of the engine cover incorporated in the steam engine of the invention;

FIG. 34 is a side view of a high pressure steam injection port and low pressure steam exhaust ducting;

FIG. 35 is an end view of the portion of the front furnace cover shown in FIG. 29;

FIG. 36 is an internal section end view of the front cover incorporated in the boiler furnace of FIG. 29;

FIG. 37 is an end view of another portion of the rear cover for the boiler furnace of FIGS. 29 and 34;

FIG. 38 is a side elevation view of the deaerator incorporated in the steam engine of the invention;

FIG. 39 is a longitudinal sectional view of the vacuum pump incorporated in the invention;

FIG. 40 is a side elevation view similar to FIG. 2 illustrating a portion of the steam engine of the invention along with the make-up water system;

FIG. 41 is a view of another cam actuating mechanism for a slide valve incorporated in the invention;

FIG. 42 is a view similar to FIG. 15 showing another portion of the cam incorporated in the high pressure valve cam mechanism of the invention;

FIG. 43 is a view similar to FIG. 18 illustrating another cam actuating mechanism for a slide valve incorporated in the invention;

FIG. 44 is a section view of another cam actuating mechanism located next to item 295 on 281 (FIG. 43) when a four stage arrangement is used;

FIG. 45 is an end view of an automatic advance mechanism incorporated in the steam engine of the invention;

FIG. 46 is a side elevation view of a further type of automatic advance mechanism incorporated in the invention; and

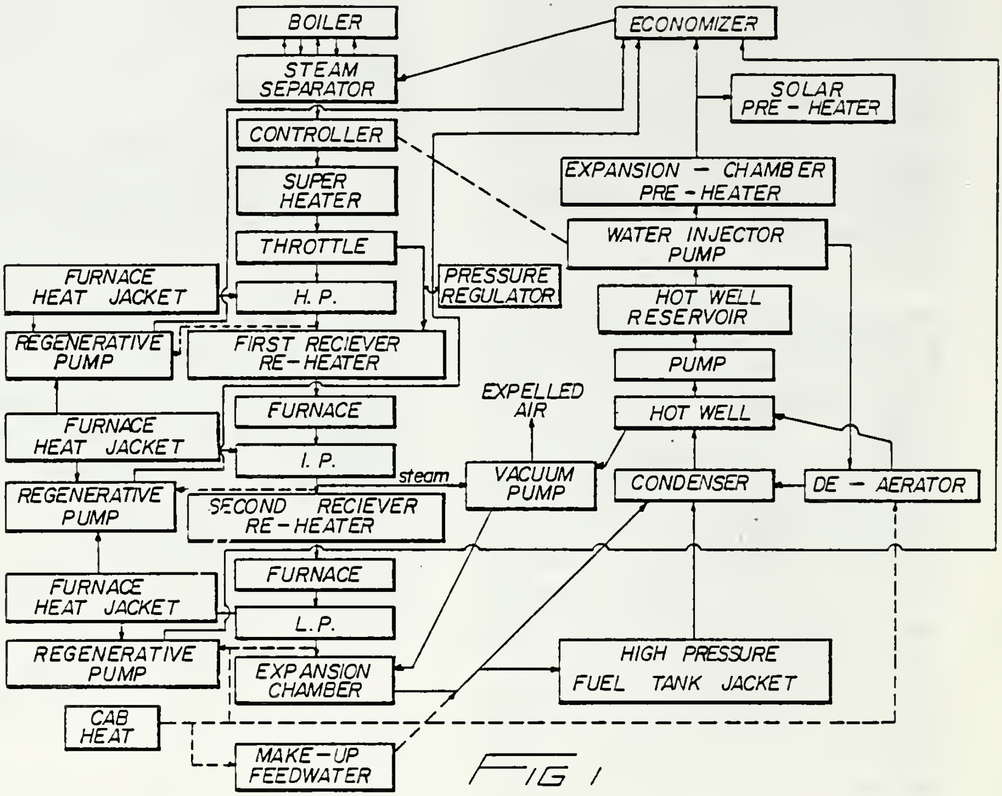

BOILER
STEAM SEPARATOR
ECONOMIZER
SOLAR PRE - HEATER
CONTROLLER
SUPER HEATER
EXPANSION - CHAMBER PRE - HEATER
WATER INJECTOR PUMP
THROTTLE
PRESSURE REGULATOR
FURNACE HEAT JACKET
H. P.
HOT WELL RESERVOIR
REGENERATIVE PUMP
FIRST RECIEVER RE-HEATER
PUMP
EXPELLED AIR
FURNACE
HOT WELL
FURNACE HEAT JACKET
I. P.
steam
VACUUM PUMP
CONDENSER
DE - AERATOR
REGENERATIVE PUMP
SECOND RECIEVER RE-HEATER
FURNACE HEAT JACKET
FURNACE
L. P.
REGENERATIVE PUMP
EXPANSION CHAMBER
HIGH PRESSURE FUEL TANK JACKET
CAB HEAT
MAKE-UP FEEDWATER

FIG 1

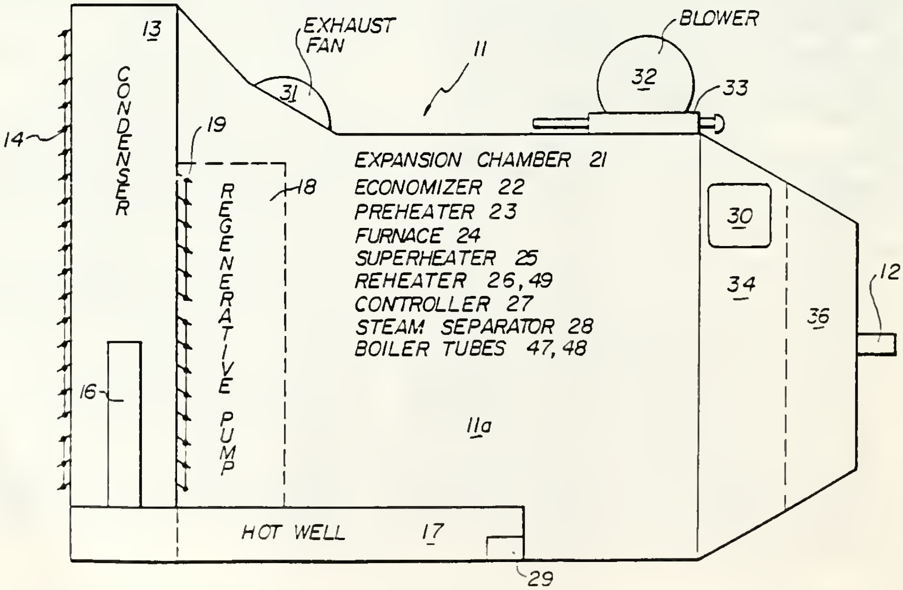
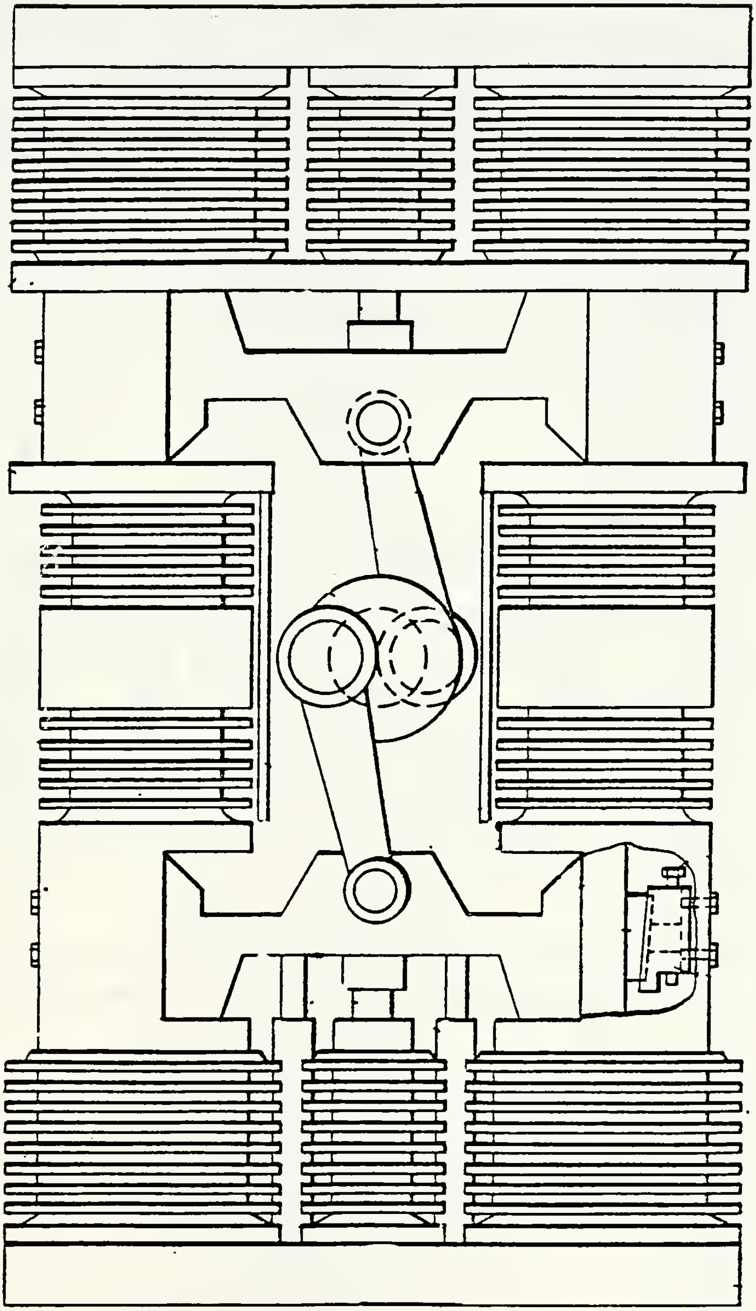

13
CONDENSER
EXHAUST FAN
31
11
BLOWER
32
33
14
19
18
REGENERATIVE PUMP
EXPANSION CHAMBER 21
ECONOMIZER 22
PREHEATER 23
FURNACE 24
SUPERHEATER 25
REHEATER 26, 49
CONTROLLER 27
STEAM SEPARATOR 28
BOILER TUBES 47, 48
30
34
36
12
16
11a
HOT WELL 17
29

FIG 2



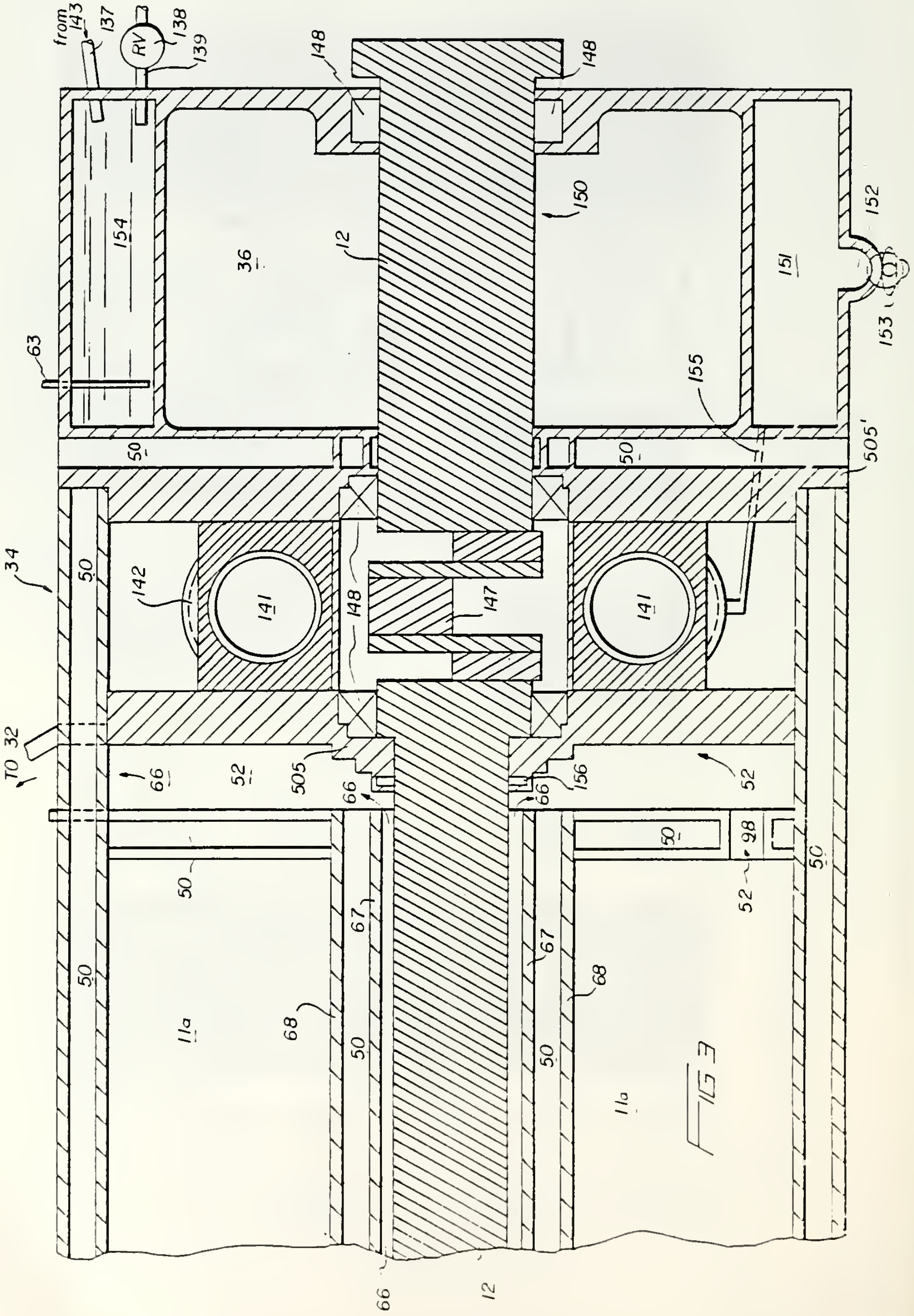

from 143
RV
TO 32

FIG 3

APPENDIX C

TEST DATA REPORT EXCERPTS

CHRONOLOGICAL TEST REPORT

June-September 1985

Assembly test and dimensional confirmations for high pressure (Hp), intermediate pressure (Ip), and low pressure (Lp) cylinder assemblies including cross arms and cross head adjusting shoes.

September-November 1985

Clearance and rotational operational checks on the cross arms, connecting rods, pistons, and cylinder assemblies.

December 1985-January 1986

Fitting and assembly of the steam chest, valve guides, valve stems and push rods, rocker arms, and cam shaft sleeves. Checked the cam plate assembly in the expander for operation and clearances. Assembled the cross members, connecting rods, and piston assemblies in the expander and checked the rotational motion.

February-March 1986

Fitting and assembly of the expander rotating assembly and associated interconnections. Electric driven slow speed rotation of the expander to breakin bearings and confirm concept.

April-June 1986

Initial assembly of the cams and centrifugal advance mechanism for machining clearance tests and assembly. Vacuum pump assembly operational checks and cycling operation characteristics.

June-July 1986

Assembly of expander, boiler, condenser, hot well, and accessories on the frame to establish fitting and total arrangement of the Unitary Steam Engine.

July-August 1986

Service and pressure checks on the condenser to assure integrity of the unit. Setup bench operational tests of the cam assembly/centrifugal advance mechanism for rotational checks and adjustments. Fabrication and fitting of the recuperator section of the boiler.

September-October 1986

Assembly and fitting of major boiler components and ductwork for proper orientation and checkout of operating characteristics. Dismantling and reassembly of intermediate pressure section of the expander to alleviate binding and replace ceramic pistons with brass. Bench test fire of propane burner after checkout of ignition system. Test fire individual propane burners and observation of flame patterns.

November-December 1986; January-February 1987

Separation of major components to allow fit up and assembly of boiler tube coils, superheater coils, reheater tubes, economizer coils, and air preheat sections.

March-May 1987

Checkout of the condenser hydraulic drive system. Operational system check of the bearing lubrication system. Assembly, fitting, and checkout of rocker arm and valve assemblies. Installation and fitting of Hp, Ip, and Lp piston rings. Packing adjustments and hand rotation for fit and clearance checks and adjustments of rotating members.

June-July 1987

Fit and installation of reheater tubes with clearances checked during assembly. Final rotational checks of the valve assemblies and engine timing. Operational check of the starter. Check of ignition and distribution system installed on Engine. Dry operational check of the throttle.

August 1987

Assembly of the complete Unitary Steam Engine which includes the expander, boiler, condenser, and controls. Multiple checks of electrical circuitry and control system were accomplished. The 32-volt primary blower produced 10 in. water column static pressure during its operational check. All valve springs were checked for displacement measurements.

August 29, 1987

The initial test firing of the assembled Unitary Steam Engine was made with propane with an attempted switch over to No. 1 fuel oil. The firing marked the start of the operational debugging of the prototype and associated design modifications to sustain operational firing.

The 32-volt dc blower motor operation could not be maintained without Engine rotation and subsequent alternator electrical generation. Therefore, a 3/4 horsepower, 110 volt ac motor was installed on that primary air blower to assist during this startup phase. A second test firing on propane was then accomplished confirming this modification. The burner design was not suitable for liquid fuel and redesign was necessary.

September 1987

Fabricated a new fuel atomizing system and single burner cone. After bench testing and firing, installed that single burner cone in the Engine.

September 30, 1987

Test fire in the Engine with one burner cone installed. Sustained firing with No. 1 fuel oil for approximately 1 minute and could hear water boiling after shutdown. This indicates a heat conversion principal has been confirmed.

October 10, 1987

After installation of the remaining burner cones a test firing on No. 1 fuel oil was conducted. Firing was accomplished on both high and low fuel for 5 minutes. No pressure was raised as insufficient water was in the boiler.

October 21, 1987

After operational debugging and modifications a test firing was conducted for 14 minutes. Again, no steam pressure was raised and the test was terminated. Further operational checks and analysis determined that throttle redesign was desirable and that an improvement for boiler water charging and flow control were necessary.

November 5, 1987

A number of modifications were completed on the engine, including a new throttle and solenoid fill valve control logic, prior to the test firing. That firing was for 22 minutes achieving a steam pressure of 1,100 psig and two unsuccessful attempts to engage the expander. It was then determined that modification of the starter was required as well as isolation of the valve water system.

November 12, 1987

Installed water valve isolating headers and a continuous starter preparatory to this test firing. Fired for 19 minutes achieving a maximum steam pressure of 1,425 psig. Attempted two separate starts on the expander and experienced binding during this process. Analysis determined that lubrication independent of Engine rotation was required. Inspection revealed that the Hp ceramic valves were fractured.

November 21, 1987

Installed an auxiliary drive on the lubricating pump and replaced the Hp ceramic valves with steel and brass construction. Fired for 18 minutes achieving a maximum steam pressure of 1,000 psig. The expander again froze up when the throttle was opened during starter engagement. Review of video indicated that the expander physically reversed a few degrees and held itself in a braking mode during start-up attempts. This led to investigating the valve timing. At this point the analysis of all the previous testing led to the following conclusions: time to complete this project within contract limitations had become critical; funding for any major modifications was not available; a complete disassembly, inspection, and rebuild should be accomplished; and an operational test was still desirable. Within those constraints, it was determined that modifications to enable the abbreviated test should be done.

December 5, 1987

Reprofiled the timing mechanism for the Hp valves and disconnected the injector and water circulating pumps. Further simplification included removal of the water valve and control circuits to isolate the boiler system. This prevented the opportunity for a continuous operational test run but allowed sufficient steam generation for a proof-of-concept rotational start-up test.

Fired for 9 minutes achieving a maximum steam pressure of 1,250 psig. The expander locked up during the start-up attempt. Subsequent efforts to rotate the expander were unsuccessful. Major component disassembly revealed that there was an oil/water emulsion in the A and D LP cylinders and a broken 1/4 in. copper tubing on the oil lubrication return.

After consultation with DNRC it was determined that this would be the final test of this project because of time, money, and major disassembly requirements. Therefore, no further modifications, testing, or analysis will be done on this contract.

Unitary Steam Engine Test Data

October 21,1987

11:58am	Ignition
	fuel oil @ 23 gal
	fuel oil pressure @ 115 psi
12:03pm	Pressure indication on throttle
	transition shroud @ 120 F
12:04pm	Valve water @ 180 kPa (26.1 psi)
12:06	Shroud @ 190 F
12:07	Valve water pressure dropping
12:08	Small exterior fire below fuel oil preheat lines
12:11	Shroud @ 220 F
	Valve water @ 0 psi.
12:12	Fuel oil off
12:16	Shroud @ 260 F
	combustion air blower continuing to run for cooldown

Unitary Steam Engine Test Data

November 5, 1987

Time	Comments	Transition Shroud Temperature	Control Column Pressure
11:47am	Ignitor on, Electricity on, Primary air on, Fuel on		
11:48	Ignition with hi fuel		
	Fuel oil @ 22-1/4 gal		
11:49		80 F	
11:53		110 F	
11:54	Additional lo fuel		
11:54+			150 psig
11:55			200
11:57		180 F	
11:58		210	250
12:00pm		250	300
12:01			400
12:02			500
12:03	Primary air full open		600
12:04			800
12:05		375	900
12:06			1000
12:06+	Throttle open		1100
	First start		700
	Throttle closed		
12:07	Steam leak on water column		1000
12:08	Throttle open		
	Second start		
	Throttle closed		500
12:09			650
12:10	Fuel off	430	500
	Stack temp @ 90 F		
12:11			400
12:12	Water leak directly below valves		
	Fire in area of primary air blower - rubber hose protecting wiring		
12:13	Fuel oil @ 20 gal		150
12:15	Ignition with hi fuel to confirm plug firing		
12:16			200
12:21	Primary air continuing for cooldown	400	180

Unitary Steam Engine Test Data

November 12, 1987

Time	Comments	Transition Shroud Temperature	Stack Temp.	Control Column Pressure
11:01am	Ignitor on, Electricity on, Primary air on, Fuel on			
11:02	Ignition with hi fuel,			
	Ignitor off as no fire on #1&2			
11:03	Re-ignition with hi fuel			
	Fuel Oil @ 20 1/2 gal			
11:04	Additional lo fuel			
11:05		80 F	55 F	0 psig
11:06		105	58	100
11:07	Small leak on throttle stem			300
11:08		132	58	500
11:09	Steam leak on top of column			700
	Water leak on bottom of column			
11:10		180	60	925
	Steam pressure leak on top of column			
11:11				1425
	Start continuous starter			
	Try to open throttle- very difficult			
11:12				1300
11:13	Reverse starter- engine binding			
11:14	Reversing starter- engine binding			400
11:15	Fuel off	280	68	300
	Fuel on - no fire - fuel off			
11:16	Fuel on and ignition			
11:17	Fuel oil @ 19 gal			
		280	69	300
11:18				390
11:19				420
11:20				500
11:21	Reversing starter- engine binding			590
11:23	Fuel off	370	82	850
11:24	Solenoid valve actuation for water column fill			
11:26	Fuel oil @ 18 1/2 gal			550
11:28		380	87	480
11:33		340	88	280
	Three LP exhausts are warm- # C is not			
11:38		315	89	100

Unitary Steam Engine Test Data

November 21, 1987

Time	Comments	Transition Shroud Temp.	Stack Temp.	Control Column Pressure
4:09:30pm	Ignitor on, Electricty on, Primary air on, Fuel on Ignition with hi fuel; Fuel oil @ 19 gal			
4:10	Additional lo fuel			
4:11	Start oil lubrication			
4:12		60 F	<50 F	100 psig
4:13		80		300
4:13:45	Start continuous starter			
4:14	Pressure varying	92		600
4:15		110		450
4:16		125		470
4:17:30				580
4:18		150		650
4:19	Circulating injector fitting water leak			
		180		680
4:20	Fuel oil @ 17 1/2 gal			
		190	50	680
4:22	Steam leak under valves, infra red shroud temp 220 F			
		210	50	800
4:23		250	52	900
	Sharp clunk within engine			
4:24	Steam leak on top of column and top of engine			
		260	51	1000
4:25	Rotating engine	270	51	1000
4:26:40	Low water column			1000
4:27	Opening throttle, Water/steam leak on bottom of column			
4:27:41	Engine froze up at 10 degree before TDC			
4:27:58	Fuel off, Shutdown			
		315		520
4:28	Oil fire underneath engine			
4:30	Fuel oil @ 17 gal, Can hear steam leak into engine			
		320	58	600
4:32		295	58	480
4:34				300
4:35	Open throttle to relieve steam pressure, fire again between engine and boiler			
4:38	Steam pressure leak on top intermediate stage -wall to lid and wall to body			
		220		
4:39	Tried to rotate engine with no success			

Combustion Efficiency Tests

A Neotronics Portable Combustion Optimizer (PCO) Model 960-1 was used on December 5, 1987, to test the combustion efficiency of the Unitary Steam Engine and Boiler. Two test ports were drilled: one in the boiler shroud and one in the stack. The PCO continuously monitors carbon monoxide, oxygen, and temperature difference of the flue gas. The PCO estimates efficiency based on oxygen content of the flue gas and the temperature difference between the probe location and termocouple located on the machine.

Fuel oil No. 1 was used for the tests. Combustion efficiencies taken at the shroud port of the Unitary Steam Engine ranges from 70.5 to 77.3 percent efficiency, including losses due to the carbon monoxide content of the flue gas. The efficiency at the stack readings are higher (89.3 to 91.3 percent) because more heat is reclaimed in the additional sections of the boiler. The carbon monoxide readings were also lower in the stack.

The efficiencies calculated by the PCO are different than those presented because the unit is calibrated for No. 2 diesel fuel, and the base temperature (where the unit was located) was higher than the ambient temperature (38°F). Also, the PCO does not incorporate efficiency losses due to carbon monoxide. The high carbon monoxide readings indicated that fuel oil was hitting the (cold) boiler tubes and smoldering. This was due to the boiler being designed to burn a vapor like ethanol, and then burning oil in it. Future revisions will incorporate appropriate differences.

Unitary Steam Engine Test Data

December 5, 1987

Time	Comments	Transition Shroud Temp.	Stack Temp.	Control Column Pressure
2:45pm	Ignitor on, Electricity on, Primary air on, Fuel on, Oil lubrication on, Fuel oil @ 18 gal			
2:47	Rotate engine with starter			
2:52	Ignition with hi fuel	<50 F	<50F	
2:53	Additional lo fuel	62		
2:55				150 psig
2:56	Rotating engine	100		300
2:57	Steam leak on throttle	120		720
2:58		145		1020
2:59	Water leak on water column	165		1250
2:59:20	Open throttle Steam leak on water column cover			
3:00	Internal steam leak in expander; perhaps the intermediate steam chest seal			400
3:00:30		200	52	480
3:01				480
3:01:30	Fuel off, engine bound Fuel @ 17 1/2 gal			
3:02		208	52	250
3:03:30	Reverse starter, engine bound	195	55	100
3:06	Throttle open	180	56	0
3:10		150	58	
3:15		130	60	
3:18	Shut down primary air Outside air 46 F	120	60	

Excess Air, CO2 and Efficiency w/CO Calculations

BACKGROUND DATA				
Location	Butte-Cozby	Butte-Cozby	Butte-Cozby	Butte-Cozby
Building	Unitary	Unitary	Unitary	Unitary
Boiler No.	Steam Engine	Steam Engine	Steam Engine	Steam Engine
Date, time	12/5/87	12/5/87	12/5/87	12/5/87
@Pressure. Temp.				
Outside Air	ID & FD	ID & FD	ID & FD	ID & FD
Listed Fuel Input				
Listed Fuel Output	450 psi	700 psi	1100 psi	Shutdown
Year of Combustor	1986	1986	1986	1986
Type Boiler	oil, EtOH.	oil, EtOH.	oil, EtOH.	oil. EtOH.
TEST INFORMATION				
Fuel Type	2.0	2.0	2.0	2.0
Time	3;50 pm	3;52 pm	3;55 pm	4:00 pm
Load Condition	high fire	high fire	high fire	high fire
INSTRUMENT READINGS FROM PCO-961				
% Oxgyen	17.0	17.1	17.0	17.0
Temp Diff, C	95.0	119.0	132.0	115.0
CO, ppm	1,162.0	1,246.0	1,242.0	112.0
Efficiency Read out	76.9	72.0	70.1	68.8
Combutor Air Temp, F	38.0	38.0	38.0	38.0
CALCULATED ITEMS BASED ON O2 & CO				
Shroud Temp, F	203.0	246.2	269.6	239.0
Temp of Water/steam	459.0	506.0	557.0	459.0
Temp difference	(256.0)	(259.8)	(287.4)	(220.0)
Working diff T, C	91.7	115.7	128.7	111.7
Calculated CO2	2.62	2.55	2.62	2.62
Excess air	476.5	492.8	476.5	476.5
Efficiency w/CO, MTF	77.30	72.37	70.52	73.79

Excess Air, CO2 and Efficiency w/CO Calculations

BACKGROUND DATA				
Location	Butte-Cozby	Butte-Cozby	Butte-Cozby	Butte-Cozby
Building	Unitary	Unitary	Unitary	Unitary
Boiler No.	Steam Engine	Steam Engine	Steam Engine	Steam Engine
Date, time	12/5/87	12/5/87	12/5/87	12/5/87
@Pressure, Temp.				
Outside Air	ID & FD	ID & FD	ID & FD	ID & FD
Listed Fuel Input				
Listed Fuel Output	450 psi	700 psi	1100 psi	Shutdown
Year of Combustor	1986	1986	1986	1986
Type Boiler	oil, EtOH.	oil, EtOH.	oil, EtOH.	oil, EtOH.
TEST INFORMATION				
Fuel Type	2.0	2.0	2.0	2.0
Time	3;50 pm	3;52 pm	3;55 pm	4:00 pm
Load Condition	high fire	high fire	high fire	high fire
INSTRUMENT READINGS FROM PCO-961				
% Oxgyen	17.0	17.1	17.0	17.0
Temp Diff, C	95.0	117.0	132.0	115.0
CO, ppm	1,162.0	1,246.0	1,242.0	112.0
Efficiency Read out	76.9	72.0	70.1	68.8
Combutor Air Temp, F	38.0	38.0	38.0	38.0
CALCULATED ITEMS BASED ON O2 & CO				
Stack Temp, F	55.0	75.0	84.0	59.0
Temp of Water/steam	449.0	506.0	557.0	449.0
Temp difference	(394.0)	(431.0)	(473.0)	(390.0)
Working diff T, C	15.0	18.9	26.1	15.0
Calculated CO2	2.62	2.55	2.62	2.62
Excess air	476.5	492.8	476.5	476.5
Efficiency w/CO, MTF	91.34	90.53	89.30	91.43

Corrected for actual stack (not shroud) temp

APPENDIX E

SUPPORTIVE DESIGN AND CALCULATIONS INDEX

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File No.	Title	Investigator	Date
10-1	Stress Analysis of Reciprocating Members	R. Fullmer	6/28/84
10-2	Weight Calculations for Reciprocating Parts	"	7/5
10-3	Thermo Analysis/Process Schematic	"	7/9
10-4	Steam Consumption Rate Analysis	"	7/16
10-5	Indicated Horsepower	"	7/17
10-6	Steam Flow/Valve Operation Velocity/Acceleriation	"	7/17-23
10-7	Cam Analysis	"	7/25-8/7/84
10-8	Booster Pump Calculations	"	8/8
10-9	Support Frame Analysis	A. D. Miller	7/5
10-10	Calculation of Piston Velocity	"	7/19
10-11	Bearing Shaft Diameter	"	7/23
10-12	Bearing Load & Life Calculations	"	8/10
10-13	Critical Crankshaft Speed	R. Fullmer	8/9
10-14	Valve Port Openings	K. Cozby	7/27
10-15	Centrifugal Force on Connecting Rods vs. Strength of Bolts	"	8/2
10-16	Boiler Tubing Lengths	J. Cozby	9/12
10-17	Ethanol Fuel Requirement & Combustion	A. Miller	9/14
10-18	Superheater Tube Design	"	9/13
10-19	Boiler Heat Transfer	"	9/18
10-20	Recuperator Heat Transfer	"	9/21
10-21	Air Heater & Ethanol Preheat	"	9/21
10-22	Flue Gas Heat Calculation	"	9/24
10-23	Energy Balance	"	9/24
10-24	Control-Liquid Level Design	J. Cozby	9/26
10-25	Control - Pressure, Furnace	"	9/28
10-26	Steam Traps	"	10/8
10-27	Condenser Heat Rejection Calculations	A. Miller	10/9
10-28	Booster Pump Drive	J. Cozby	10/11
10-29	Instrumentation	"	10/ /84
10-30	G - Forces	"	
10-31	Motor Oils	API_Kendall	
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APPENDIX F

DRAWING INDEX; EXCERPTED

SIMPLIFIED DRAWING LOG:

*1. General Drawing Plan View
*2. General Drawing Side Elevation
*3. General Drawing Water/Steam System
*4. General Electrical Drawing
5. Condenser, Hotwell, & Accessories: End Elev. (Rev.)
6. Transition from Engine to Boiler
7. Side Elevation of Bioler (Rev.)
8. Top View of Boiler
9. Front View of Transition and Boiler
10. Cross Sections of Boiler
11. Boiler Support Frame
12. Boiler Front Cover Cross Section Side Elevation
13. Boiler Cross Section End Elevation
14. Boiler Rear Cover Cross Section, Side Elevation
15. Boiler Front Cover
16. Damper Assembly
*17. General Drawing Quadrant
*18. Crankshaft Plan View
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21. Crankcase Wall "B"
22. Crankcase Walls "C & D"
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24. Cross Member Assembly
25. Cross Member Details
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27. H.P. Cylinder
28. Valve Operator Section Side Elevation
29. Valve Operator Section Plan
30. Valve Operator Section Plan
31. L. P. Injector Cam
32. L. P. Exhaust Cam
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37. H. P. Cam Step 3

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47. Furnace Side Cover PL/Brg. Housing
48. Mid Cover PL/Brg. Housing
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54. Liquid Level Control and Steam Separator
55. Control Panel
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58. Furnace Air Ducting (Rev.)
59. Boiler (Recuperator Sect.) to Condenser Connections
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61. Revised Vacuum Pump Valve Mechanism
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102. Furnace Heat Balance Diagram (MS2)
103. Steam Generator Heat Balance
104. Heat Balance Diagram
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106. Liquid Level Control
107. Control and Drive System for Condenser Fan
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109. Furnace Control
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121. I. P. Exhaust ass'y, Plan View
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148. L. P. Exhaust Duct, Side Elev. (Rev.)
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153. Mid Pl & Perimeter Insulation Front Elev.

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157. Piston Velocity/Acceleration vs Crank Angle
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163. H. P. Cam, Steps 5 & 7 BDC
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170. (ReDrawn) Switch Connections
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191. Exhaust Stacks and Front Ribs
192. Fuel Lines - Recuperator Section
193. Fuel Oil Burner: Cone - Nozzle Ass'y.

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